New Scientist

WEEKLY 18 June 2022

What is time?
How do we sense time?
Can we live without time?
How do we make the most of our time?
Why does time only move forwards?
How much time does evolution take?
Is time the key to a theory of everything?
What affects our perception of time?
When will time end?

The nine biggest questions about the most mysterious dimension of all

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WE'RE LOOKING FOR THE
best ideas in the world
ON BEHALF OF OLDER PEOPLE

The Ryman Prize is an international award aimed at encouraging the best and brightest thinkers in the world to focus on ways to improve the health of older people.

The world's ageing population means that in some parts of the globe – including much of the Western world – the population aged 75+ is set to almost triple in the next 30 years.

Older people face not only the acute threat of COVID-19, but also the burden of chronic diseases including Alzheimers and diabetes.

At the same time the health of older people is one of the most underfunded and poorly resourced areas of research.

To stimulate fresh efforts to tackle the problems of old age, we're offering a NZ$250,000 (£130,000) annual prize for the world's best discovery, development, advance or achievement that enhances quality of life for older people.

The Ryman Prize is awarded each year by the Prime Minister of New Zealand. It was first awarded in 2015 to Gabi Hollows, co-founder of the Hollows Foundation, for her tireless work to restore sight for millions of older people in the developing world.

Since then world-leading researchers Professor Henry Brodaty, Professor Peter St George-Hyslop, Professor Takanori Shibata, Dr Michael Fehlings and Professor Miia Kivipelto have all won the prize for their outstanding work.

In 2021 Professor Kenneth Rockwood, a Canadian geriatrician, academic and anti-ageism campaigner whose research into frailty has had a huge impact, was awarded the prize by the Right Honourable, Jacinda Ardern, Prime Minister of New Zealand.

If you have a great idea or have achieved something remarkable like Kenneth and our six other prize winners, we would love to hear from you.

Entries for the 2022 Ryman Prize close at 5pm on Friday, July 15, 2022 (New Zealand time).

Go to **rymanprize.com** for more information.

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Cover image: Julia Lee

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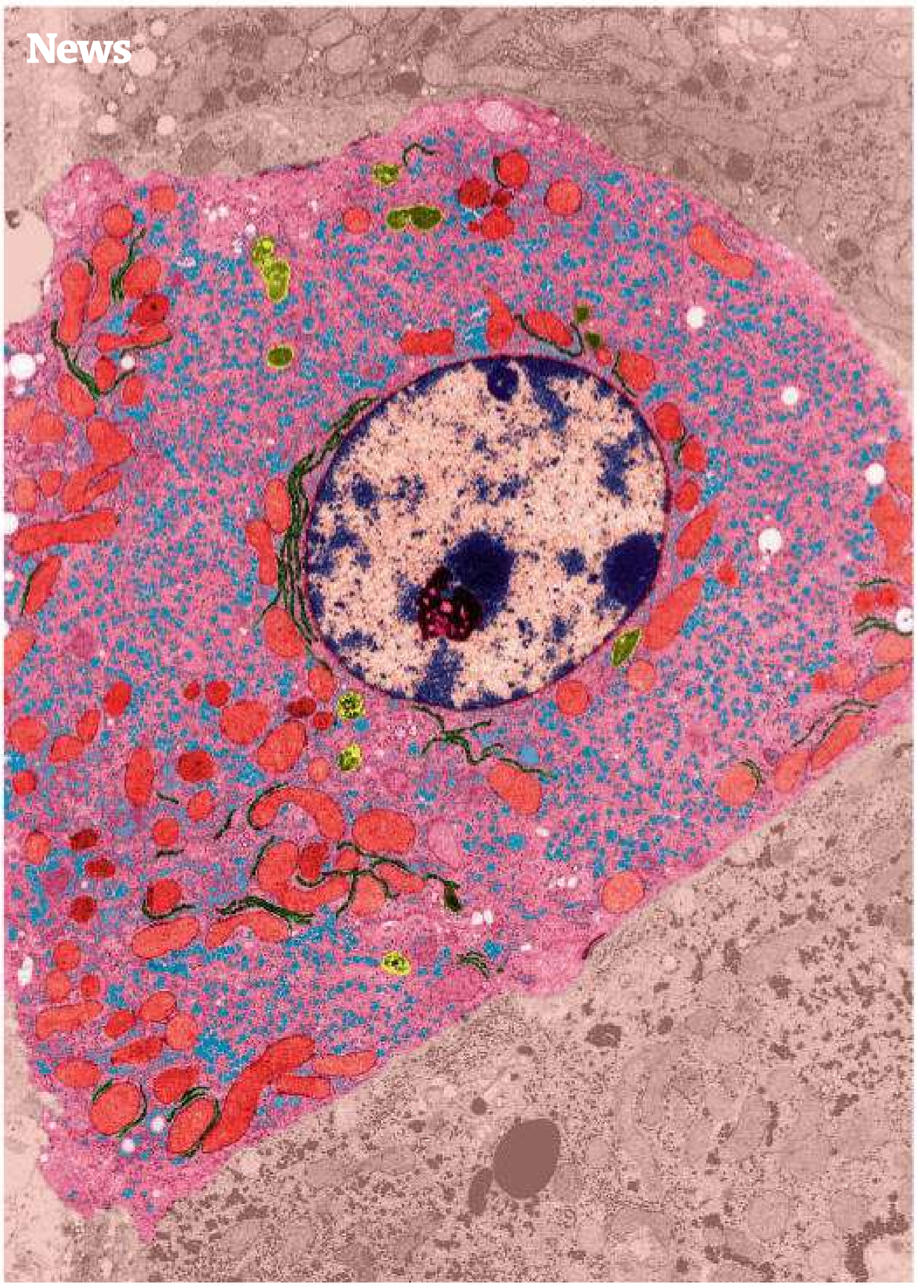

DENNIS KUNKEL MICROSCOPY/SCIENCE PHOTO LIBRARY

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Land of fire and ice: Iceland

Join a wonderful tour of Iceland's majestic landscapes, with days devoted to volcanic adventure and nights spent gazing at the aurora borealis. Accompanied by volcanologist Tamsin Mather and geologist Simon Matthews, you will see erupting geysers, boiling hot springs and stunning glaciers. From 29 October for eight days. The cost is £2549.

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Podcast

Weekly

The team ask when we should admit the 1.5°C global warming target is dead, and what it might mean when we do. Podcast host and editor Rowan Hooper gets excited about *Top Gun: Maverick* and finds a way to make it about science. Plus, the team discuss chickens and how archaeological blunders caused confusion over when they were domesticated.

newscientist.com/nspod

PARAMOUNT PICTURES

The drone ranger How realistic is *Top Gun: Maverick*'s technology?

RICHARD LEVINE/ALAMY

Highs and lows The sale of CBD products has recently rocketed

Video

Plastic fantastic

Watch as "superworm" beetle larvae munch their way through a block of polystyrene. Bacteria found in the guts of *Zophobas morio* larvae produce enzymes that can digest the commonplace material, potentially providing a new way to recycle plastics in the future. Researchers are interested in developing an artificial system that mimics this activity.

youtube.com/newscientist

Newsletter

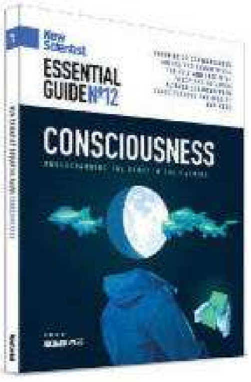
Health Check

Reporter Clare Wilson delves into the truth behind medical marijuana. Many of its reported benefits are thought to come from a chemical compound called cannabidiol (CBD) and sales of dietary supplements containing pure CBD have now skyrocketed. Do these products work, or are they just snake oil?

newscientist.com/ health-check

Podcast

> **"Perhaps drones are just as likely to disobey orders as our friend Maverick"**



Essential guide

Consciousness is the ghost in our machine – our feeling of being and our relationship with the world. But what does it consist of and why do we have it? Delve into the ultimate mystery of being with the latest *New Scientist Essential Guide*.

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STAY IN TUNE
WITH INFLATION?

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New adventures in time

The mysteries of the fourth dimension are a never-ending source of fascination

THERE is nothing quite so simultaneously familiar and enigmatic as time, the focus of this week's issue. Which is perhaps what always makes it such a joy to indulge in our unique ability to explore the many ongoing mysteries of time – and to chase a better understanding of the most puzzling dimension of all.

We can't even agree on what time is, though many people suspect answers could lie in the mismatch between how it manifests in general relativity – Einstein's theory of gravity – and quantum mechanics, which describes the behaviour of subatomic particles and forces (see page 39). Figuring that out could finally lead us to a quantum theory of gravity (see page 45). That is proving to be a difficult quest, but fresh clues are arriving all the time. Just this week, researchers discovered a new kind of time crystal (see page 12), strange oscillating materials that may offer a new window on events at the quantum scale.

We can't physically go back in time – for now, at least (see page 40). But that doesn't stop us from venturing into the deep past through the fossil record, which is revealing that evolution happens on two timescales at once (see page 43), or by studying stars and galaxies millions of light years away. This form of time travel has just received a boost with the latest release of data from the Gaia space telescope (see page 8), featuring details on the chemical composition of almost 2 billion stars to help us build a better picture of our galaxy's history. We can also speculate about the deep future, not least the ultimate question – will time ever end (see page 48)?

> "Some of the most fascinating questions about time have to do with how we relate to it"

But arguably some of the most fascinating questions about time have to do with how we relate to it. In the past few years, neuroscientists have made strides in understanding how our brains measure time (see page 41) and psychologists have demonstrated the role our bodies play in warping our perceptions of its passage (see page 42). They even have surprising proposals for how we might rethink our relationship with time – for example, by tapping into the fact that each of us only enjoys a limited supply – to live more fulfilling lives (see page 46). ■

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AN IMPORTANT MESSAGE FROM PROFESSOR NICK LEMOINE CBE MD PHD FMEDSCI, CHAIR OF THE MEDICAL RESEARCH FOUNDATION

Gifts in Wills could be the key to protecting the future of human health

Our experience of COVID-19 shows how suddenly a global health challenge can appear. As someone interested in science, you will understand that while nobody can predict what we will face next, we can be certain that the future will bring many more threats to human health.

As Chair of the Medical Research Foundation – the charitable arm of the Medical Research Council – I have seen the incredible impact that individuals who remember the Foundation in their Wills can have on the future of our health and wellbeing here in the UK. These gifts fund research and researchers which can have far-reaching implications for human health.

With a gift in your Will you can play a key role in providing the science that will protect the health of future generations.

Right now, the Foundation is funding research to tackle antimicrobial resistance, and investing in researchers like Dr Myrsini Kaforou – who will make the fight against antimicrobial resistance her life's work.

Without support at the crucial early stages, researchers like Dr Kaforou can be forced to abandon their passion and leave science altogether, with an immeasurable loss to future human health. Gifts in Wills provide the long term funding and security that allows the Foundation to invest in projects like Dr Kaforou's and lay the foundations for quality research in years to come.

Your Will can fund the rational response to health challenges that medical science provides.

> **"As scientists, our duty is to secure the future of research for the generations that follow."**
>
> Professor Fiona Watt, Patron of the Medical Research Foundation and Director of the European Molecular Biology Organization.

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"The funding I received through the Medical Research Foundation will be transformative for my research." Dr Myrsini Kaforou

While we don't know what the future holds for human health in the UK, we do know that research, and the brilliant scientists driving that research forward, are the key to meeting those challenges for years to come.

But many of these scientists rely on the generosity and foresight of fellow members of the public – people like you, who understand the power of science and are willing to leave a gift to medical research in their Wills. At the Medical Research Foundation, over 90% of our voluntary income comes from individuals who choose to include a gift in their Will – they are crucial in the Foundation's ability to fund research that will enable the next generation of scientists to make real world discoveries in the future.

I firmly believe that a gift in your Will to the Medical Research Foundation is an excellent investment and will have a lasting impact on science and on the future of human health in the UK.

Please consider this very special gift today.

Professor Nick Lemoine CBE MD PhD FMedSci
Chair of the Medical Research Foundation

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Evolution debate
New mutations appear vital for long-term adaptation **p10**

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Brains can be warmer than the rest of our bodies **p14**

Green guardians
Trees protect art from air pollution in Rome **p18**

Quantum advantage
Exotic computers have the edge in some tasks **p19**

Covid in pregnancy
Infection linked to developmental delays in some babies **p20**

BRIAN MATTHEWS/SOLENT NEWS/SHUTTERSTOCK

A dead pink-footed goose on a beach in Dumfries, UK

Environment

Bird flu hits UK seabirds

Deadly avian influenza is spreading in the UK's globally significant populations of gannets and geese, reports **Adam Vaughan**

CONSERVATIONISTS fear that a highly pathogenic bird flu is to blame for a growing wave of mortality in UK seabirds, which were already facing severe pressure from climate change and overfishing.

The H5N1 avian influenza has killed wild birds including cranes in Israel, Dalmatian pelicans in Greece, knots (a type of shorebird) in the Netherlands and now several UK seabird species, primarily gannets. More than 383,000 bird deaths from the virus have been counted by the World Organisation for Animal Health (WOAH) since October 2021.

About 16,500 of a population of 43,000 Svalbard barnacle geese, which migrate between Scotland's Solway Firth and Norway's Svalbard, are estimated to have died from flu during the recent winter, says James Reynolds at the Royal Society for the Protection of Birds, a UK charity.

"But the epicentre now is… in Shetland and in the Northern Isles [of Scotland] and it's also showing up in the Western Isles and around mainland sites," says Reynolds.

"Wildlife has been particularly affected this [bird flu] season," says a spokesperson at WOAH. "We are seeing significant mortality in a wider range of wild birds and in various geographical areas, which is unusual."

Birds have had to cope with avian influenza for thousands of years. However, the illness currently devastating wild birds – predominantly caused by the H5N1 virus – is a recent issue that has its origins in intensive poultry production in eastern Asia. This form of flu was first spread through the movement of poultry and is now doing so through the migration of wildlife.

> "We are seeing significant mortality in a wider range of wild birds and in various areas"

While the flu is unwelcome in wildfowl such as the Svalbard barnacle goose, it is a particularly acute threat for seabirds because they tend to be long-lived species with low reproductive rates. "So even once this wave of disease passes, it's going to take the populations much longer to recover compared with quite fast-breeding species like geese," says Stuart Butchart at the non-profit organisation BirdLife International.

The loss of seabirds in the UK has global ramifications because the country is home to so many of them: about two-thirds of the world population of gannets and great skuas are in the UK.

Conservationists say the flu's impact compounds existing long-term, human-caused pressures. "It's particularly concerning for the seabirds because they're being impacted already by fisheries, climate change, disturbance and other threats," says Butchart.

Reynolds says that in the short term, better monitoring and surveillance of flu in wild birds is needed, along with swift removal of carcasses to avoid more birds being infected. The Scottish government held an urgent meeting on 14 June to see how the RSPB and authorities can better coordinate a national response to the unfolding disaster.

The risk to human health is seen as low. However, people are advised not to touch birds they suspect of being killed by flu. If they find one, they are asked to call a UK government helpline.

Butchart says the loss of wild birds could still have a "huge impact" on the poultry industry by forcing chickens, ducks and geese to be kept indoors again, a step which he says will have "massive economic consequences". UK consumers have only been able to resume buying free-range eggs since early May, after UK bird flu control measures introduced last November were relaxed. ▮

Astronomy

Rewinding the Milky Way

The European Space Agency has released a new tranche of data from its Gaia space telescope, and now we can look back into the history of our galaxy, finds **Alex Wilkins**

OUR map of the Milky Way has been upgraded and it now lets us rewind the paths of stars to look back in time. The data set that enables this, released by the European Space Agency (ESA)'s Gaia space telescope, includes the detailed chemical make-up and speeds of almost 2 billion stars.

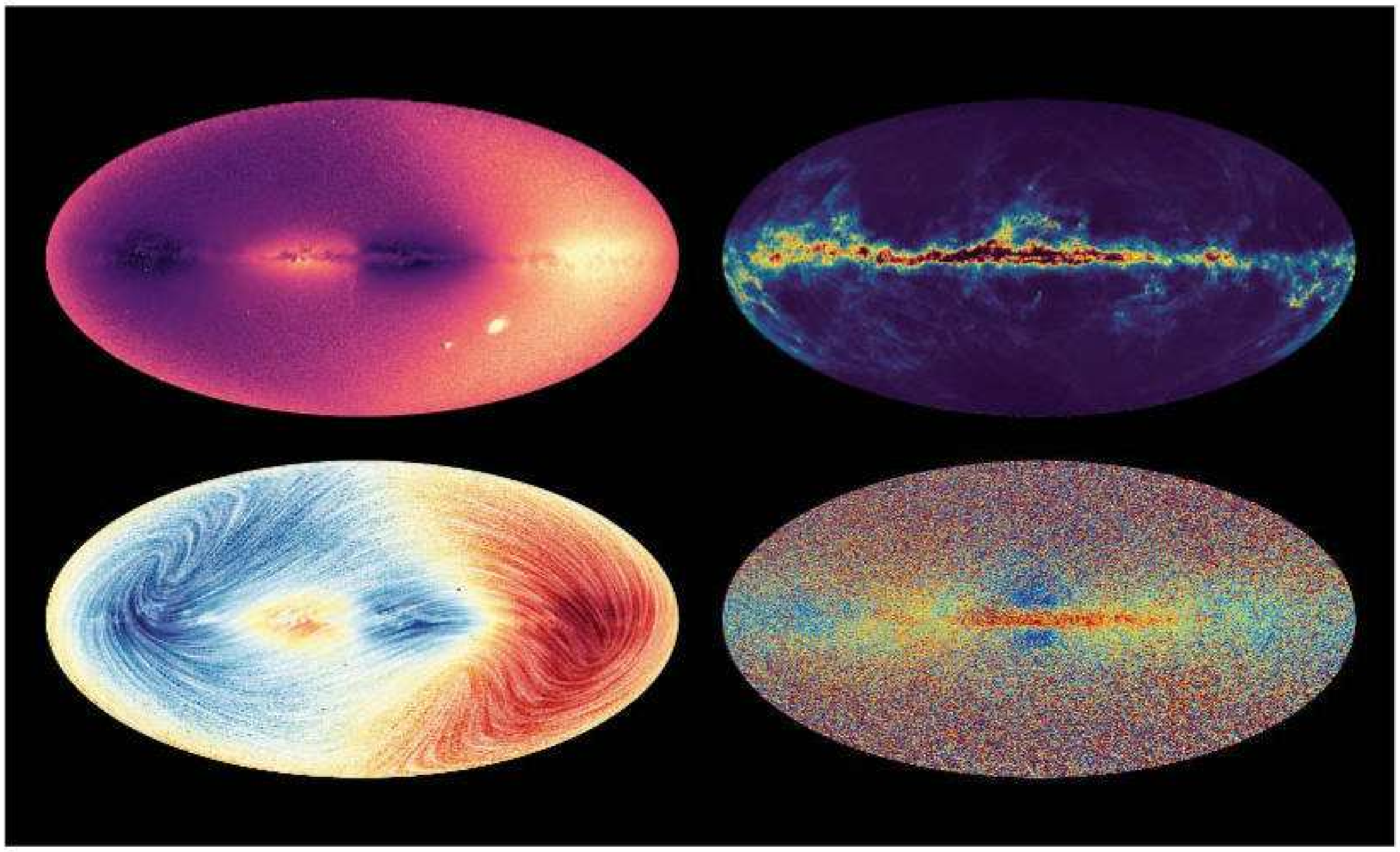
> "You can point to a particular star and say, 'I want to know where that was billions of years ago'"

From its vantage point 1.5 million kilometres from Earth, Gaia has been measuring already known stars and seeking new ones since its launch in 2013. The first data release, published in 2016, contained information on the brightness and positions of 1.1 billion stars, and a second release in 2018 followed up with the colours, temperatures and radii of a total of 1.7 billion stars.

Now, ESA has published information on almost 2 billion stars overall, increasing the number that we know the chemical compositions of by a factor of 10, and the number of radial velocities – how fast they are moving away from or towards us – by a factor of five. It also provides greater detail on star temperatures, colours and masses.

What's more, the information hoard contains the largest known catalogues of binary stars, asteroids and moons, as well as millions of other galaxies.

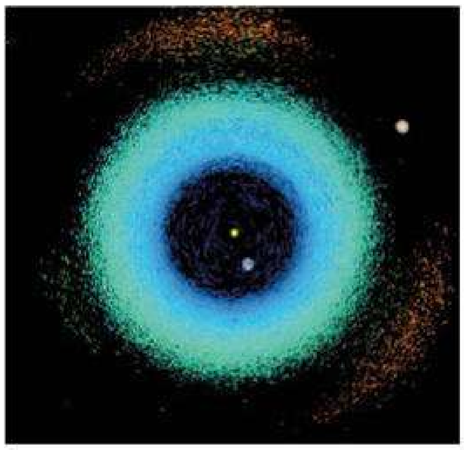
Gaia can now produce more detailed chemical and radial velocity maps than ground-based telescopes, which will allow us to trace the Milky Way's evolution. "Gaia is like a time machine that allows us to look back and infer the history of our galaxy," says George Seabroke at University College London.



The Gaia telescope team has produced beautiful maps of the Milky Way

2 billion

We now have data on nearly this many stars in the Milky Way



A snapshot of asteroids orbiting the sun on 13 June

RIGHT & ABOVE: ESA/GAIA/DPAC

To create this chemical map, which tells us where stars form and where they came from based on the metals they contain, Seabroke and his colleagues analysed Gaia's latest spectroscopic data. This contains varying frequencies of starlight, which is linked to the chemical make-up of the stars.

Galaxy evolution

Measurements from Gaia's spectrometer also helped produce the most detailed radial velocity map of the Milky Way. This tells us which stars are moving away from or towards us when looking at the galaxy from the side on. When combined with the motion of the stars as seen from Gaia, this 3D map can help us trace how the galaxy might have evolved.

"You can run time forwards and backwards when you know their orbits," says Seabroke. "So, for a particular star, you can point to it and say, 'I want to know where that star was billions of years ago', and you can do that with these models."

Repeated measurements of the same stars has helped separate out stronger signals from statistical noise. One consequence of this is that Gaia appears to be able to detect small variations and vibrations on some star surfaces that it wasn't originally designed to pick up.

One particular type of tsunami-like vibration that changes a star's shape, known as a starquake, was detected on some stars where it shouldn't have been possible according to current theories. "Gaia is opening a goldmine for 'asteroseismology' of massive stars," said Conny Aerts at KU Leuven in Belgium in an ESA statement.

ESA has performed some preliminary analysis on the data set, but more discoveries will arrive in the coming months and years as the scientific community examines it in more detail. ■

Climate change

Net-zero pledges for countries and firms are on the increase

James Dinneen

MORE than a third of the largest public companies, along with countries representing most of the world's economy, now have targets to reduce their net greenhouse gas emissions to zero. However, many of these net-zero pledges are lacking basic details about how they will be achieved or verified.

In a report, a research consortium called the Net Zero Tracker took stock of the publicly available climate pledges of more than 4000 entities, including cities, states, countries and publicly trading companies. Since the consortium first went through this exercise in March 2021, there has been a significant improvement.

Countries representing 91 per cent of the global economy have made net-zero pledges compared with just 68 per cent last year. Those pledges now apply to countries that create 83 per cent of global greenhouse gas emissions and are home to 80 per cent of the world's population, up from 61 per cent and 52 per cent last year.

Corporations, too, have made improvements, as only a fifth of companies tracked by the researchers had announced plans for net zero by the end of 2020, compared with a third now. Nearly half of fossil fuel companies have made net-zero pledges.

While ambition has grown, how it will be achieved and how progress will be confirmed remains unclear. According to the report, "an alarming lack of credibility still pervades the entire landscape", whether it is a dearth of information on how carbon offsets will be used to meet targets or a scarcity of interim goals.

To improve the quality of net-zero targets, and not just the quantity, the report suggests extending regulations to clearly define what commitments and reporting mechanisms should be required to make a net-zero pledge. ▮

Artificial intelligence

No sign of a machine mind yet

Claims that an AI has become sentient have sparked excitement, but the reality is more mundane, reports **Matthew Sparkes**

A GOOGLE engineer has reportedly been suspended by the company after claiming that an artificial intelligence he helped to develop had become sentient. "If I didn't know exactly what it was, which is this computer program we built recently, I'd think it was a seven-year-old, eight-year-old kid," Blake Lemoine told *The Washington Post*.

Lemoine released transcripts of conversations with the AI, called LaMDA (Language Model for Dialogue Applications), in which it appears to express fears of being switched off, talks about how it feels happy and sad and attempts to form bonds with humans by mentioning situations that it could never have actually experienced. Here is everything you need to know.

Is LaMDA really sentient?

In a word, no, says Adrian Weller at The Alan Turing Institute in London. "LaMDA is an impressive model, it's one of the most recent in a line of large language models that are trained with a lot of computing power and huge amounts of text data, but they're not really sentient," he says. "They do a sophisticated form of pattern matching to find text that best matches the query they've been given that's based on all the data they've been fed."

Adrian Hilton at the University of Surrey, UK, agrees that sentience is a "bold claim" that isn't backed up by the facts.

So what convinced Lemoine that LaMDA was sentient?

Neither Lemoine nor Google responded to *New Scientist*'s request for comment. But it is certainly true that the output of AI models in recent years has become surprisingly, even shockingly good.

Our minds are susceptible to perceiving such ability – especially when it comes to models designed to mimic human language – as evidence of true intelligence. Not only can LaMDA make convincing chit-chat, but it can also present itself as having self-awareness and feelings.

"As humans, we're very good at anthropomorphising things," says Hilton. "Putting our human values on things and treating them as if they were sentient. We do this with cartoons, for instance, or with robots or with animals. We project our own emotions and sentience onto them. I would imagine that's what's happening in this case."

KENZO TRIBOUILLARD/AFP VIA GETTY IMAGES

Will AI ever be truly sentient?

It remains unclear whether the current trajectory of AI research, where ever-larger models are fed ever-larger piles of training data, will see the genesis of an artificial mind.

"I don't believe at the moment that we really understand the mechanisms behind what makes something sentient and intelligent," says Hilton. "There's a lot of hype about AI, but I'm not convinced that what we're doing with machine learning, at the moment, is really intelligence in that sense."

Weller says that, given human emotions rely on sensory inputs, it might eventually be possible to replicate them artificially. "It potentially, maybe one day, might be true, but most people would agree that there's a long way to go."

How has Google reacted?

The Washington Post claims that Lemoine has been placed on suspension after seven years at Google, having attempted to hire a lawyer to represent LaMDA and sending executives a document that claimed the AI was sentient. Its report notes that Google says that publishing the transcripts broke confidentiality policies.

Google told the newspaper: "Our team, including ethicists and technologists, has reviewed Blake's concerns per our AI principles and have informed him that the evidence does not support his claims. He was told that there was no evidence that LaMDA was sentient (and lots of evidence against it)."

Lemoine said on Twitter: "Google might call this sharing proprietary property. I call it sharing a discussion that I had with one of my co-workers." ▮

Evolution

Debate about the source of evolution's diversity may have been settled

Michael Le Page

THERE is a long-standing debate in biology about the relative importance of existing variation versus new mutations in evolution. Now, this has been put to the test in an experiment with bacteria that ran for 2000 generations – and new mutations quickly won out.

After 500 generations, the pre-existing variation no longer mattered and all further evolution was due to new mutations, says Minako Izutsu at Michigan State University.

"Five-hundred generations in our experiment is 75 days. It's really short," says Izutsu. "I thought the effects of standing variation would last longer."

Mutations in the genomes of organisms provide the variation on which natural selection can act – that is something biologists agree on. What they have long argued about is whether evolution acts mainly on past mutations or has to hang around waiting for new mutations, and to what extent evolution can be shaped by chance mutations.

Evolution experiments involving plants and animals typically start with a diverse population and run for only a few generations, so the changes seen depend on standing – that is, pre-existing – variation, says Richard Lenski, also at Michigan State University, the study's co-author.

By contrast, experiments with bacteria normally start with genetically identical bacteria, says Lenski, and so the evolution seen is entirely due to new mutations.

***Anemone coronaria* flowers come in a diversity of colours**

ALAMY

Izutsu and Lenski set up 72 populations of *Escherichia coli* bacteria ranging from genetically identical ones to highly diverse ones. All the bacteria were taken from the Long-term Experimental Evolution Project that Lenski started in 1988, which he is now handing over to another group after running it for 75,000 generations.

The 72 populations of bacteria, which had been fed on glucose, were fed another nutrient (D-serine) to force them to adapt to a new environment.

"The genetic variation that was there to start with really mattered early in the experiment, maybe for the first 50 to 100 generations," says Lenski. But by 500 generations, the starting variation no longer mattered at all (bioRxiv, doi.org/hzr4).

"It was a bit surprising, to me at least," says Lenski.

"The results provide pretty compelling evidence that standing variation contributed to very early stages of evolution in these bacteria, but that long-term adaptation appears to require new mutations," says David Stern at the Howard Hughes Medical Institute in Virginia.

What is less clear is whether this also applies to sexually reproducing organisms. Stern thinks long-term evolution in animals and plants is also dominated by new mutations, but says he has long arguments with colleagues who think standing variation dominates.

"We simply don't have the right kind of data at the moment to settle this question," he says. ▮

Ancient humans

AI finds evidence of human fires from a million years ago

AN ARTIFICIAL intelligence tool has revealed hidden evidence of fire at a 1-million-year-old archaeological site in Israel. Applying the technology at other sites could revolutionise our understanding of when and where humans first began controlling fire.

To identify whether our ancient ancestors used fire at a site, archaeologists look for signs that prehistoric bones are discoloured or that stone tools are warped in a way that is consistent with exposure to temperatures of 450°C or more. But such evidence is rarely found at sites more than 500,000 years old.

Last year, a group of researchers in Israel unveiled a deep-learning AI tool that can identify subtler signs of fire caused by exposure to temperatures of between 200°C and 300°C. The team trained the algorithm by gathering chunks of flint from the Israeli countryside, heating them to set temperatures and then tasking the AI with identifying subtle changes in the flint's response to UV light.

Now, the team, working with Michael Chazan at the University of Toronto in Canada, has used the algorithm to look at flint tools from a 1-million-year-old ancient human site called Evron Quarry in Israel.

The location was chosen because it had the same kind of flint used in the earlier study, "but there was just no reason to think there would be evidence of burning", says Chazan.

Yet the AI system suggested that many of the flint tools at the site had been heated, mostly to temperatures of about 400°C (*PNAS*, doi.org/hzvx).

"We might be able to see if use of fire, and cooking, was widespread about 2 million years ago"

Existing techniques confirmed that chunks of bone recovered from the site had been heated too. Chazan says no one would have bothered testing them without the AI flint results. The clustering of the heated stones and bones hints at a controlled fire rather than a wildfire.

Chazan thinks the new tool could be used to test whether fire – and cooking – was widespread between about 1.8 and 2 million years ago. ▮

Colin Barras

ATEM Mini Pro model shown.

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Quantum physics

Strange new type of time crystal has been created

Alex Wilkins

A NEW kind of time crystal has been made that could explain how these mysterious substances function and reveal the scale at which quantum effects kick in.

The existence of time crystals was proposed in 2012 by Frank Wilczek at the Massachusetts Institute of Technology. Normal crystals have patterns that repeat in three-dimensional space, creating a lattice structure. Wilczek imagined a crystal-like quantum system whose constituent parts would perpetually move to create patterns that repeat in time, instead. Because these theoretical substances required eternal movement without consuming energy, however, they appeared impossible under the laws of physics.

They didn't remain theoretical for long, though. In 2017, two teams reported that they had found a way to make a kind of time crystal that oscillates, by repeatedly firing lasers at various substances. Although the resulting systems didn't exactly follow Wilczek's original definition, these "discrete" time crystals did have certain properties that oscillated, unrelated to the firing pattern of the laser.

Now, Hans Keßler at the University of Hamburg in Germany and his colleagues have created a "continuous" time crystal using a constant source of laser light rather than the discrete bursts utilised in the earlier experiments. Keßler and his team cooled about 50,000 rubidium atoms to almost absolute zero and trapped them between two nanoscale mirrors that contained the laser beam.

10

The number of milliseconds the time crystal lasted for

The interactions between the atoms and the laser's photons – particles of light – made both the distribution of the atoms and the intensity of the photons constantly oscillate (*Science*, doi.org/gqbj9z).

This is similar to what happens in a more prosaic crystal such as ice, says Keßler. Liquid water looks the same in every direction, but when it freezes, a repeating lattice structure forms instead. And like with ice, where you can't predict where the molecules will be located, you also can't pinpoint when the repetition starts in the time crystal, due to a quirk of quantum mechanics.

"The analogy of our system to ice is that we know the frequency of the oscillation, but we cannot predict its time phase – when our time crystal gets formed. The observation… is closer to the original idea by Wilczek," says Keßler.

Although other people have made continuous time crystals using "periodic drives" such as intermittent lasers, the continuity here is novel, says Samuli Autti at Lancaster University, UK. "One particularly impressive detail is that, because the driving technique used in the paper is not periodic, the authors can reliably draw a phase diagram of the time crystal, just like we can draw a diagram showing where water becomes solid as a function of pressure and temperature."

Understanding such graphical representations of when the state of a substance changes means the system can be more reliably produced and experimented with.

This latest time crystal lasts only for about 10 milliseconds, but if that can be extended, then new quantum features could be introduced to the system as the number of atoms in it is varied. This could help us understand the scale at which quantum effects take hold, says Keßler. ▮

ADRIENNE BRESNAHAN/GETTY IMAGES

Crystals normally make patterns in space rather than in time

Palaeontology

Dinosaur may have had a reptile version of a belly button

Carissa Wong

A HERBIVOROUS parrot-beaked dinosaur that lived in what is now China 130 million years ago may have had the reptile equivalent of a mammalian belly button.

"When I saw this, my mind said umbilical scar!" says Phil Bell at the University of New England in Australia.

Most mammalian embryos gain nutrients from a placenta through an umbilical cord, which eventually falls off to leave an abdominal scar, or belly button.

In birds and reptiles, the embryo is attached via blood vessels to a yolk sac, which provides nutrients within the egg. After the animal hatches, the yolk sac is absorbed into its body, leaving a linear abdominal scar. Unlike in humans, this scar usually disappears after a few days to weeks.

Until now, it was unknown if dinosaurs – which also laid eggs – had umbilical scars that lasted for more than a few weeks.

Bell and his colleagues imaged the scar in the dinosaur – a psittacosaurus – using a technique called laser-stimulated fluorescence, which revealed that the scar was about 10 centimetres long and unlikely to have been caused by physical trauma. "It has all the characteristics of a reptilian belly button," he says.

By comparing the length of the femur bone in the specimen with other psittacosaurus fossils known to be of animals that were about 6 years old, the team established that the individual was a similar age, suggesting it kept its belly button throughout life (*BMC Biology*, doi.org/gp9svq).

It is unknown how widespread umbilical scars may have been across dinosaur species. "Maybe 5 per cent of adult dinosaurs might have had them, based on our observations of modern reptiles," says Bell. ▮

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Genetics

An epigenome-editing injection

Switching off a gene in mouse liver cells lowered cholesterol and should cut heart disease risk

Michael Le Page

A ONE-OFF injection might permanently reduce the risk of heart disease by reversibly switching off a gene in the liver, according to a study in mice. The findings suggest that the approach used, called epigenome editing, can produce long-term changes in gene activity without the potential risks associated with permanent gene editing.

Liver cells produce a protein called PCSK9 that breaks down another protein that removes cholesterol from the blood. So blocking the PCSK9 protein, or stopping it being made, can lower cholesterol levels and should cut the risk of heart disease.

There are already cholesterol-lowering drugs that work in this way, but they require injections every few weeks because they can't be taken in pill form.

One alternative is to permanently disable the *PCSK9* gene in liver cells by editing its DNA sequence. In May, biotech firm Verve Therapeutics got the go-ahead in New Zealand to trial this in people with an inherited genetic condition that causes dangerous cholesterol levels.

NOBEASTSOFIERCE/SHUTTERSTOCK

Epigenome editing alters chemical tags on DNA to control gene activity

But such techniques can theoretically result in unwanted DNA changes, which could turn cells cancerous, although there are no reports of this happening in any gene-editing trials so far. For people with serious inherited conditions, that risk might be acceptable, but for wider use, epigenome editing could be preferable.

Instead of cutting DNA strands and altering their sequence, epigenome editing tools add or remove chemical tags that control gene activity. Because of this, there should be no risk of them causing potentially dangerous mutations.

> "It should be possible to reverse epigenomic changes if there are undesirable effects"

Angelo Lombardo at the San Raffaele Telethon Institute for Gene Therapy in Milan, Italy, and his colleagues have now delivered an epigenetic tool for shutting down the *PCSK9* gene in cells to the livers of mice. It is in the form of messenger RNA molecules, which encode a protein to edit the epigenome. Cholesterol levels in the mice were halved, and Lombardo thinks it will be possible to cut them more. "I'm sure there are ways to improve the efficacy," he says.

What's more, the researchers tested the mice at various times over 220 days and the effect lasted as long as they kept testing, suggesting it is permanent.

Other teams have only managed to create such a lasting effect by getting cells to continuously produce epigenome editors. Lombardo says his team's editor was only produced for a few days and would have then broken down and disappeared. The team presented the work at a meeting of the American Society of Gene & Cell Therapy last month.

In theory, it should be possible to reverse epigenomic changes and switch genes back on if there are any undesirable effects, says Lombardo.

The results are good, says Luca Magnani at Imperial College London. But epigenome editing isn't yet ready for testing in people, he says. ▮

Health

Brain can be a few degrees hotter than the rest of the body

HEALTHY human brains can be hotter than we thought, reaching nearly 41°C in women, according to a small study.

The findings could change how people with brain injuries are medically managed, says Nina Rzechorzek at the MRC Laboratory of Molecular Biology in Cambridge, UK.

Normal brain temperature is generally assumed to be the same as that of the rest of the body – about 37 °C – yet we had no way to know for sure. People with head injuries sometimes have highly sensitive temperature probes put into their brains, but this isn't done to people who aren't undergoing medical treatment.

Rzechorzek's team looked at the brains of 40 healthy people – half of whom were women – using a technique called magnetic resonance spectroscopy, in which MRI machines measure the temperature of different parts of the brain. This was the first time the technique has been used to measure brain temperature variation over the menstrual cycle. The study didn't include transgender people.

The brain temperature ranged from 36.1°C to 40.9°C, with the average reading being 2.5°C higher than the body temperature recorded inside the mouth. This makes sense because the brain is highly metabolically active, says Rzechorzek.

The brains of the women in the study were 0.4°C hotter during the second half of the menstrual cycle, between ovulation and menstruation, compared with the first half, and compared with men (*Brain*, doi.org/gqbvsf).

Doctors sometimes try to lower the body temperature of people with brain injuries because they are concerned that high temperatures are harmful, an approach that may need revising, says Rzechorzek. "We [have been] making an assumption that a value of, for instance, 40°C is abnormal," she says. ▮

Clare Wilson

Astronomy

Mysterious cold blobs discovered hiding in a star

Leah Crane

THE distant star AU Microscopii seems to have pockets of hydrogen that are more than 1500°C cooler than surrounding areas, and astronomers aren't sure why.

Also known as AU Mic, it is a relatively small star about 32 light years away. Laura Flagg at Cornell University in New York was testing an algorithm using 1998 Hubble Space Telescope data on AU Mic when she noticed something odd: its light spectrum showed evidence of hydrogen gas at temperatures between 725°C and 1725°C.

The star's photosphere – its outer shell, from which its light shines – has an average temperature of more than 3000°C. Flagg and her colleagues did a deeper analysis of the 1998 data, as well as new data from 2020, and found that the cool hydrogen is probably in the star itself, rather than on a nearby planet or orbiting debris (arxiv.org/abs/2206.02636). This only deepened the mystery.

"There is no obvious answer as to where in the star this cold hydrogen is coming from," says Flagg.

The researchers have two hypotheses: AU Mic may contain an uncharacteristically cold layer at the top of its photosphere, or it may have "starspots" similar to those found on our sun, but with unexpectedly low temperatures. Both of these are plausible based on observations of the sun, but AU Mic is only half the sun's mass, and neither effect has been spotted in such a small star before.

"Our understanding of stellar structure, especially for low-mass stars, is really limited," says Flagg. We need to improve this, she says, because in order to understand planets orbiting such stars, we have to be able to separate out the light that is coming from the star from that coming from the planet, which is crucial for the search for life on other worlds. ▮

Climate change

UK government admits its Net Zero Strategy doesn't add up

Adam Vaughan

LAWYERS for the UK government have been in the High Court of Justice in London defending its flagship plan for reaching net-zero emissions by 2050. Three non-profit organisations, ClientEarth, Friends of the Earth and the Good Law Project, argued that the Net Zero Strategy was in breach of the 2008 Climate Change Act over its failure to set out how much individual policies will cut emissions.

Judgment on the case was reserved on 9 June, meaning we probably won't find out who wins for months, but the case has revealed a number of important facts about the UK's approach to tackling climate change.

Last October, at the strategy's launch, government officials said it put the UK on course for its 2037 carbon target as well as earlier interim ones. But evidence presented by Richard Honey, a lawyer for the Department for Business, Energy and Industrial Strategy (BEIS), reveals that the policies and proposals that were quantified by the government only add up to around 95 per cent of the total emissions reductions needed.

That means some new measures – be it more energy efficiency in homes, more electric cars, more low-carbon hydrogen or something else – will be needed to fill the gap. The target is for an average of 193 million tonnes of carbon dioxide a year to be emitted between 2032 and 2037. The strategy says it will get to 192 million tonnes per year.

But Honey disclosed, for the first time, that quantified measures will only get the UK to 202 million tonnes per year. "We think that's really shocking," says Katie de Kauwe at Friends of the Earth.

Justice Holgate, the judge hearing the judicial review, repeatedly quizzed Honey on how the gap of 10 million tonnes could be explained. Honey said there was no calculation to explain it, but suggested it was derived from analysis by government officials. After a long explanation, Honey said: "Hopefully that helps?" Holgate said he didn't think it did. The question came up again and again, with the judge at times appearing openly frustrated. "The question I'm asking is blindingly obvious," he said at one point.

10m

Tonnes of carbon dioxide unaccounted for in UK plans

Holgate also asked why the government hadn't previously admitted the strategy would only meet 95 per cent of the carbon cuts needed for 2032 to 2037. Honey said there was concern in government that breaking down the specific emissions savings for individual policies would allow for them to be "misconstrued as predictions".

It is possible that recent changes to the assumptions underpinning climate models could help the government stay on target. Honey pointed out that the strategy was based on an assumption that greenhouse gases would trap a relatively high amount of heat, something known as global warming potential.

But in November 2021, soon after the Net Zero Strategy was published, countries at the COP26 climate summit agreed on using a much lower global warming potential. That would make it easier for the 2037 target, and earlier ones, to be met. The 5 per cent shortfall would be eliminated by the lower effect, said Honey. ▮

United Nations
Climate Change
UN CLIMATE CHANGE CONFERENCE UK 2021

UK prime minister Boris Johnson at COP26 last year

IAN FORSYTH/GETTY IMAGES

Medicine

Umbilical cord stem cell therapy treats rare disease

Clare Wilson

A GIRL who was critically ill with heart failure is doing well after receiving an experimental treatment made from her sister's umbilical cord stem cells, in the first case of its kind.

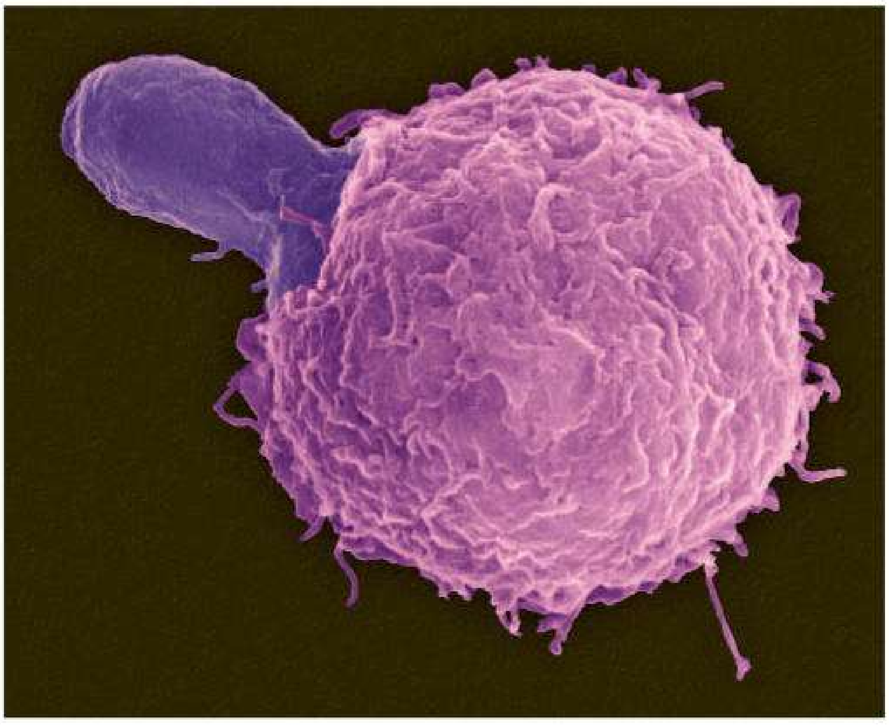
The girl, from Germany, has an inherited form of pulmonary arterial hypertension, or high blood pressure in the arteries of the lungs. This causes malformation of the blood vessels in the lungs, leading to progressive and usually fatal heart failure. Doctors had recommended that the girl, who is now 6, have a lung transplant at 3 years old, a procedure that is usually carried out on children who have less than a year to live.

Instead, she was given the experimental treatment, in which Georg Hansmann at Hannover Medical School in Germany and his colleagues harnessed stem cells from the umbilical cord of the girl's sister.

The cells were grown in a dish. Periodically, the nutrient liquid they were bathed in was changed and the old liquid was stored. Three years ago, it was infused into blood vessels in the girl's lungs and heart over six months.

"It's reasonable to assume there's something going on with this treatment"

The girl, who was breathless at rest and could only walk slowly, improved over the following months. She now has no limits to her exercise capacity. She also grew 10 centimetres within the first three months of treatment, having had no growth in height or weight in the preceding year (*Nature Cardiovascular Research*, doi.org/gqbkht).


DENNIS KUNKEL MICROSCOPY/SCIENCE PHOTO LIBRARY

A differentiating stem cell from umbilical cord blood

However, she still has high blood pressure in her lungs and may need further treatment, says Hansmann.

Stem cells have the potential to grow into different kinds of tissue and are being tested in many experimental treatments. They can be obtained in small quantities from various parts of the body and made in the laboratory from skin cells.

Stem cell treatments usually involve putting the cells into someone's body, which can cause an immune reaction. In the girl's case, the cells were grown in a dish, where they released biochemicals into the liquid they were bathed in. It is these biochemicals that seem to promote tissue healing.

The girl's treatment used mesenchymal stem cells, which are involved in making and repairing skeletal tissues.

These cells have been tested to see if they could repair heart muscle after heart attacks. While this didn't lead to lasting benefits and studies found no trace of the transplanted cells in the heart muscle, some recipients had short-term improvements, suggesting that the cells released chemicals that promote healing.

The girl had been given two standard medicines for her condition before the stem cell treatment, which may have helped, says Martin Wilkins at Imperial College London.

But when Hansmann's team investigated samples of the stem cell liquid she received, they found high levels of biochemicals that are thought to promote healing, while suppressing inflammation, including prostaglandin E2.

This biochemical tends to be rapidly broken down in the body, so other compounds may be having an effect, says Wilkins.

"There does appear to have been an improvement both in her biochemical [measurements] and in her functional capacity," he says. "It's reasonable to assume there's something going on here". ▮

Quantum physics

Physicists have made a quantum boomerang

Karmela Padavic-Callaghan

A STRANGE phenomenon known as the quantum boomerang effect, in which particles return to their starting point, has been demonstrated for the first time.

David Weld at the University of California, Santa Barbara, and his colleagues cooled hundreds of thousands of lithium atoms to near absolute zero in a vacuum-sealed box. They used lasers to arrange the atoms in a line and keep them in a particular quantum state that they hoped would reveal the boomerang effect.

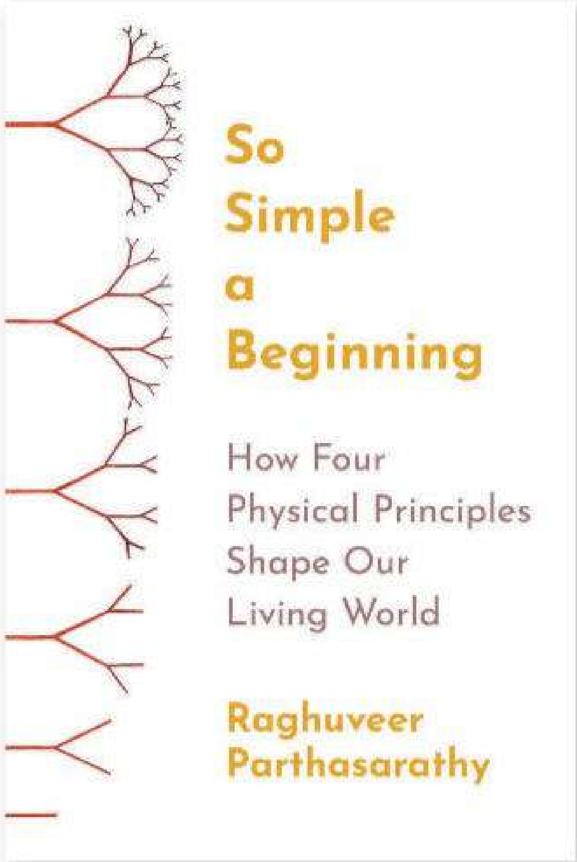
Weld and his colleagues then used the laser to nudge the atoms. This resulted in them going from having zero average momentum to having a positive average momentum.

If the same change happened to a ball, it would roll away, but because of the quantum boomerang effect, the researchers found that the atoms' average momentum soon returned to zero.

Theorists had originally proposed that this boomerang effect – of particles returning to their original positions – could happen with electrons moving inside a crystal filled with particles of dirt. However, that has proved difficult to demonstrate and study. Weld and the team sidestepped that difficulty by instead focusing on very cold atoms that can be precisely manipulated with lasers.

The researchers presented the new experiment at the APS Division of Atomic, Molecular and Optical Physics conference in Orlando, Florida, earlier this month.

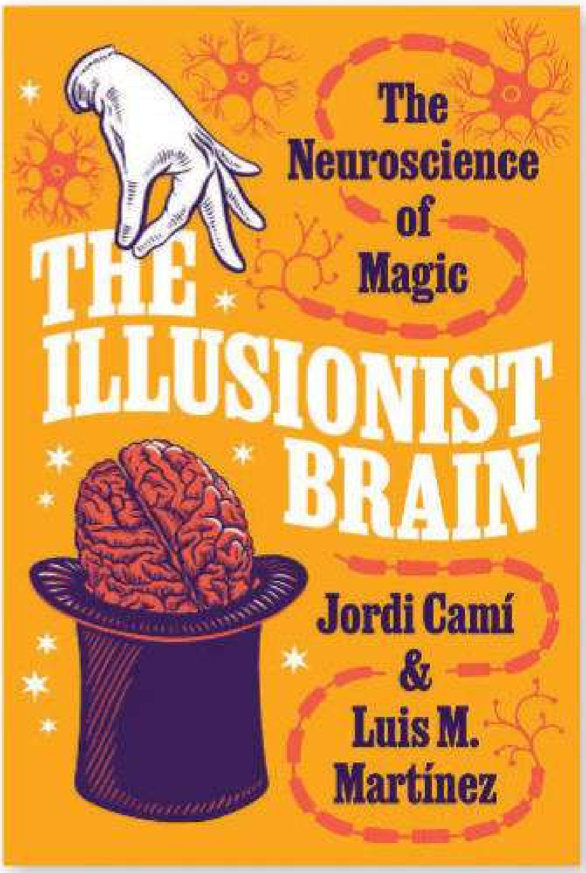
The next goal is to determine if boomeranging happens when supercold atoms interact with each other very intensely, says Weld. The behaviour of such very coordinated atoms isn't well understood, so seeing them boomerang could uncover something new about quantum physics. ▮



A biophysicist reveals the hidden unity behind nature's breathtaking complexity

"Hands down the most beautiful book I've ever read.... The intersection of biology and physics might be the most underappreciated cross-over in the sciences."

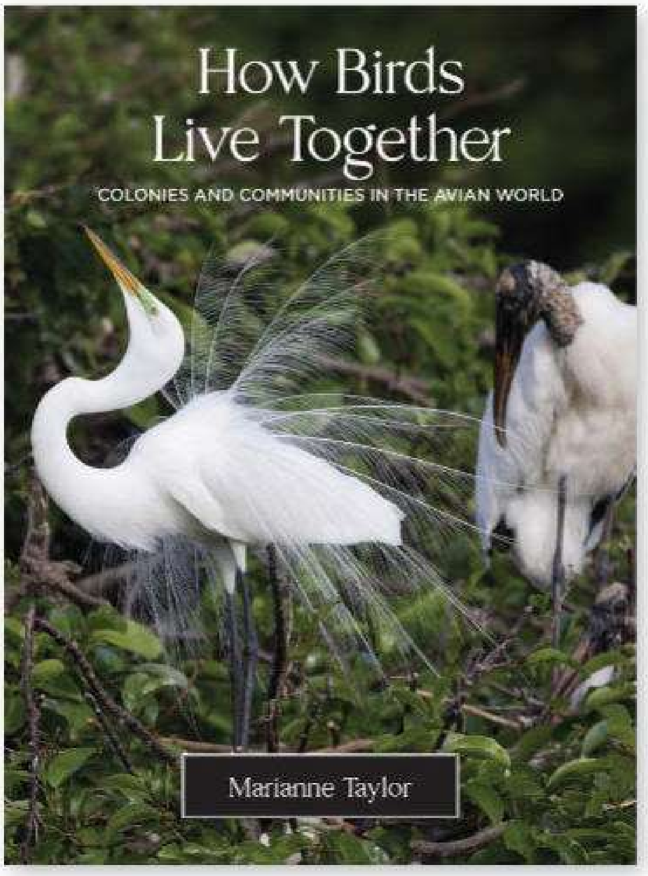
—Nicole Barbaro, *Bookmarked*



How magicians exploit the natural functioning of our brains to astonish and amaze us

"The most up-to-date and comprehensive introduction to the emerging field of neuromagic."

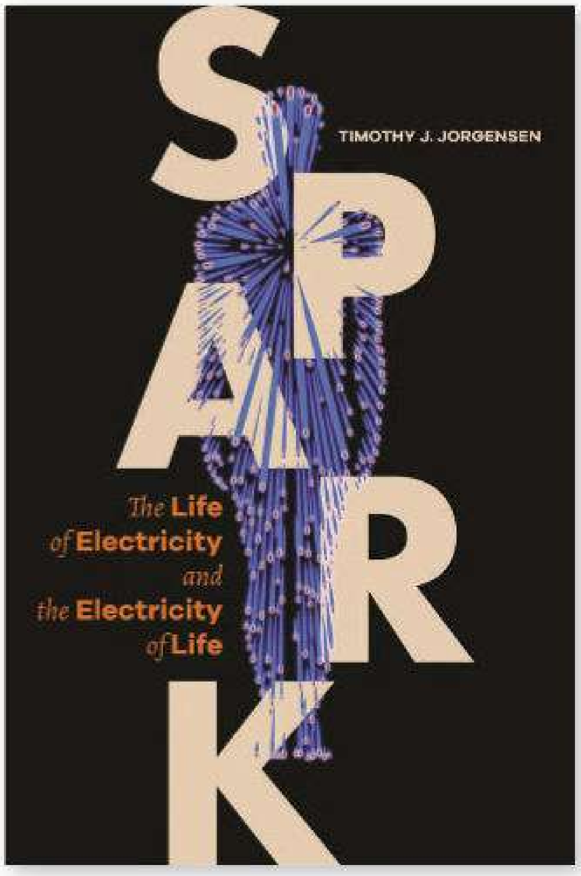
—Rodrigo Quian Quiroga,
author of *NeuroScience Fiction*



A beautifully illustrated exploration of the ways birds cohabit

"A quirky, eclectic and informative mix about birds from all compass directions."

—Phil Slade, *Another Bird Blog*



A fresh look at electricity and its powerful role in life on Earth

"[A] chatty, wide-ranging tour of electricity's role in biology and medicine."

—Jerome Groopman, *New Yorker*

Pollution

Trees protect Raphael paintings

Dirty air that threatens Renaissance frescoes in Italy can be cleaned up by leaves

Priscille Biehlmann

HISTORICAL monuments and artwork are vulnerable to the damaging effects of air pollution, but there might be a simple way to reduce the problem: plant trees that soak up contamination.

Particulate matter emitted from car brakes can be highly damaging to historical monuments and artwork. Over time, it accumulates on surfaces, creating dark layers and discolouration that often result in irreversible damage.

In the search for solutions, Aldo Winkler at the National Institute of Geophysics and Volcanology in Rome and his colleagues decided to assess the role trees could play in reducing the impact of such pollution on the artwork in the Villa Farnesina. The villa, in central Rome, was built early in the 16th century. It is famous for its frescoes, many of them created by the painter Raphael and regarded as masterpieces of the era.

"Villa Farnesina is the perfect place to do this kind of study because it houses these fantastic historical works of art and it's in an urban area that has a lot of vehicle traffic," says Winkler.

Along with his colleagues, he tested whether the leaves of trees in the nearby road and in the villa's gardens accumulate vehicle particulate matter emitted from the busy street traffic, preventing it from reaching the frescoes inside the building.

The researchers used magnetic bio-monitoring techniques to assess the level of air pollution. Their method is based on a simple principle: the leaves of a tree in a non-polluted area should have very weak magnetic properties, if any. But as they accumulate iron-rich particulate matter, their magnetic properties intensify. These particulates come largely from the metal discs used in many car brakes, which are the main source of particulate pollution in urban settings.

Inside the villa, where there are no trees, the researchers placed lichens (*Evernia prunastri*) in various rooms. They also placed lichens outside with the trees, and left them for three months in order to see how distance from the street affects pollutant levels.

Greenery outside the Villa Farnesina in Rome can help preserve artworks inside

ALDO WINKLER

The researchers discovered that the tree leaves and lichens outside the villa were up to 40 times more magnetic than the lichens inside, indicating that the trees had a role to play in stopping particulate matter reaching the villa's rooms and its artwork.

They also found that the pollutant levels increased the closer the lichens were to the road, confirming that the artwork was more at risk the nearer it was to any traffic (*Science of The Total Environment*, doi.org/hzbt).

The researchers also found differences between how effectively different tree species can capture pollutants. For instance, the high magnetic readings recorded in the villa's evergreen cypress trees suggest they offer better protection than its plane trees.

"The next thing to do is to study which types of trees we should be planting and where in order to maximise their protective effects," says Winkler. ▮

Genetics

Test shows which bio parent gave you each bit of your DNA

A GENETIC technique can identify which parts of your genome came from your biological mother and which from your biological father. The method could be useful in cases where an individual is carrying a disease-associated gene variant by helping to establish which other family members should consider undergoing screening for the gene.

Steven Jones at the University of British Columbia, Canada, and his colleagues developed the approach using DNA sequence data from the genomes of five people, which had been analysed in previous studies. The researchers also had access to genomes belonging to the biological parents of each of the five people.

Each genome tested contained 22 pairs of non-sex chromosomes, called autosomes, with each pair containing one chromosome from the biological mother and one from the biological father.

The team applied an existing technique called Strand-seq to sort all autosomes into two sets, one from each parent, but this didn't establish which parent was which.

To identify whether an autosome came from the biological mother or father, the researchers looked for evidence of a type of epigenetic marker called DNA methylation in around 200 regions of the DNA.

"About 200 sites in the genome are methylated only in the paternal or only in the maternal chromosome," says Shai Carmi at the Hebrew University of Jerusalem, Israel, who wasn't involved in the study. "These sites are well known, and the parent-specific methylation is robust."

"The researchers were able to predict which biological parent was the source of a particular chromosome"

Using these sites as a guide, Jones and his colleagues were then able to predict which biological parent was the source of a particular autosome. They then confirmed their results by looking at the genomes of the biological parents (bioRxiv, doi.org/hx7k).

"It's a very, very cool study," says Carmi – although he thinks applications will be limited by the high cost of the equipment. ▮

Carissa Wong

Society

Mental health crisis response team cuts crime rates in Denver

Grace Wade

A PROGRAMME to address mental health emergencies without police involvement led to a drop in non-violent crime rates of 34 per cent in participating police precincts of Denver, Colorado.

Instead of individuals risking arrest for minor offences such as trespassing or public intoxication, Denver's Support Team Assisted Response (STAR) Program provides them with on-site support and directs them to further care.

STAR was trialled with a two-person team from June to November 2020, after which Denver City Council voted unanimously to scale it up. During its six-month trial, STAR responded to 748 incidents, with an average of six incidents per 8-hour shift.

Thomas Dee and Jaymes Pyne at Stanford University in California analysed criminal offences reported in all Denver police precincts before and during the programme and found that non-violent crime rates fell significantly in precincts where STAR operated compared with those where it didn't. There was no impact on rates of violent crime (*Science Advances*, doi.org/gp9p57).

"[People] might be concerned that not having police at lower-level crimes might lead to an escalation of something more violent, and that simply did not happen," says Dee.

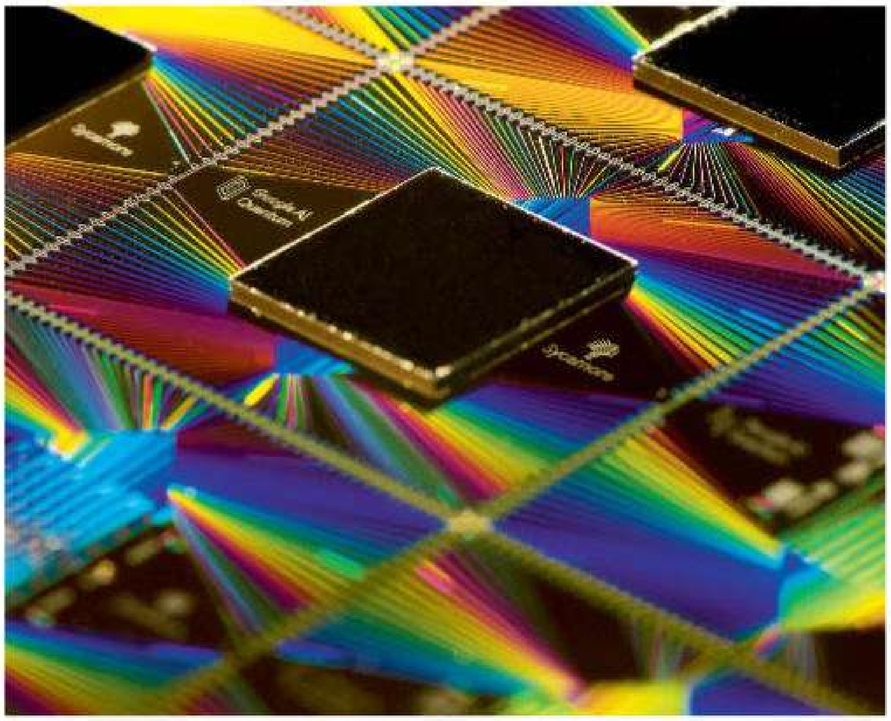
Impact on crime rates also appeared to compound over time. In June 2020, precincts saw a 29 per cent reduction in non-violent crime. By November 2020, it had dropped 38 per cent compared with precincts without STAR. On average, across the six-month pilot, the rate decreased by 34 per cent.

During the first few months of the programme's operation, Denver police officers quickly recognised the benefits of STAR and began to ask when the scheme would be expanded, says Paul Pazen, the city's chief of police. ▮

Technology

Proof quantum computers can be faster than normal ones

Alex Wilkins



GOOGLE AI

Chips from Google's Sycamore quantum computer

IT IS official – there is now proof that quantum computers can perform some tasks exponentially faster than classical computers, and it could massively boost their usefulness.

Quantum computers use quantum bits, or qubits, to measure and extract information. Unlike the bits of classical computers, which can store a 1 or 0, qubits can store multiple values at the same time. This theoretically gives them a huge speed advantage over classical computers and algorithms.

However, demonstrating that the machines have this quantum advantage, and can beat regular machines, hasn't been easy. In 2018, for instance, an example of quantum advantage – for recommendation systems like those on Netflix or Amazon – was shown to be achievable using a classical algorithm.

Now, however, Hsin-Yuan Huang at the California Institute of Technology and his colleagues have proved mathematically that not only can quantum computers have the edge on some tasks, they can be exponentially faster too.

"We now have the right mathematical framework for proving this exponential separation," says Huang.

Huang and his team used their mathematical framework to prove the speed advantage on three broad classes of quantum problems, which involved measuring and predicting properties of a quantum system, extracting information from noisy real-world signals and learning how quantum systems change over time. For each problem, they showed that the classical version of the experiment would need to be run an exponential number of times more.

> "These problems could have useful applications, like modelling complex biological systems"

Unlike previous examples of quantum advantage, like boson sampling, these problems could have useful applications, such as building sensors to detect gravitational waves or measuring complex biological systems.

The researchers then performed two experiments to demonstrate this advantage on Google's Sycamore quantum computer – made challenging by the presence of statistical noise, which wasn't covered in their proofs (*Science,* doi.org/hzbj).

The first experiment measured quantum properties of a system that is inaccessible to classical computers because of the uncertainty principle, which says, for example, that we can't be certain about both the position and the momentum of particles at the same time. The second experiment involved finding whether a quantum process was the same if it was run forwards or backwards in time, which could be important in high-energy and nuclear physics.

"The authors are able to show that there are some experiments where there's a lower bound on how many samples you're going to need using a classical computer," says Ashley Montanaro at the University of Bristol, UK. "They're able to outperform that bound even using a noisy quantum computer, which, for me, is a very impressive achievement."

While the framework that Huang and his team came up with is general, they only used it for specific classes of problems. Future work will need to prove quantum advantage for many more quantum problems, says Huang. ▮

Pregnancy

Covid-19 link to development delays

Catching the virus in pregnancy may affect an infant reaching their milestones

Clare Wilson

THE babies of women who caught covid-19 while they were pregnant during the first year of the pandemic were nearly twice as likely as other babies to experience delays in reaching milestones like babbling or grasping objects, according to a small study.

The risk of developmental delays was still small. The babies whose mothers were infected had about a 6 per cent chance of a diagnosis by the time they were a year old, compared with 3 per cent for those whose mothers didn't catch covid-19.

"We don't want to frighten people," says Roy Perlis at Massachusetts General Hospital in Boston. "The vast majority of babies don't have any delay."

Out of the 222 women in the study who tested positive for covid-19 while pregnant, 14 of their babies had developmental delays (*JAMA Network Open*, doi.org/hzb7). Transgender men weren't included in the study.

A larger study could find a bigger or smaller effect, says Perlis. Whether any developmental delays are temporary and the affected children will eventually catch up to their peers is also unknown. "It will be really important to get larger cohorts and longer follow-up," says Perlis.

Previous research has found that infections with viruses such as flu during pregnancy are linked with higher rates of autism, as well as brain conditions such as schizophrenia and attention deficit hyperactivity disorder. The explanation is unclear, but work in animals suggests an infection increases the amount of inflammatory chemicals in the bloodstream, which could affect the developing fetus's brain.

To better understand the impact of covid-19 during pregnancy, Perlis's team compared the records of 7550 women who didn't test positive for the infection while pregnant with the 222 women who did, all of whom attended hospital for various reasons in 2020.

The team looked at whether any of the babies had been diagnosed with delays in speech and physical development by their family doctors or paediatricians by the time they turned 1.

KEMAL YILDIRIM/GETTY IMAGES

A pregnant woman having an ultrasound scan during the covid-19 pandemic

Once the team adjusted the data to take into account risk factors such as race and whether the babies were born prematurely, the babies of the infected women had a 1.9-fold higher risk of delays.

In 2020, the original covid-19 variant was circulating. The team doesn't know if being infected by a different variant or being vaccinated against covid-19 would affect the results.

Women who know they caught covid-19 may be more anxious about their baby's development, which may prompt them to seek medical help if they suspect any delays, says Chris Gale at Imperial College London. "This study shows the importance of following up babies, but it's too early to say if there's definitely an impact," he says.

Anyone who is pregnant or planning to conceive should get vaccinated against covid-19, says Gale. "Pregnant women are clearly an at-risk group, for their health and for the health of their babies." ▮

Wildlife

Baby coral 'planted' on the base of offshore wind farm

FOR the first time, researchers have seeded part of an offshore wind turbine with thousands of coral larvae. If the larvae latch onto the structure and flourish, turbines in tropical waters could become havens for struggling corals.

The project, called ReCoral, is a partnership between Danish energy company Ørsted and researchers at Penghu Marine Biology Research Center in Taiwan.

First, the scientists collected coral sperm and eggs during a spawning event off the coast of Taiwan, just 50 kilometres north of Ørsted's new set of offshore wind farms. They then brought the spawn back to their lab in the city of Magong on Penghu's largest island.

After five days of incubation, there were swimming larvae ready to settle and grow into corals.

At low tide, the researchers secured a metal screen to a steel wind turbine base around 1 metre below the water level to provide enough sunlight for the algae that live within corals to photosynthesise.

The researchers then poured thousands of larvae behind the screen to encourage them to attach to the foundation. After four days, they removed this barrier with the hope that the larvae had settled onto their new homes.

"The temperature of deeper water tends to be more stable, so the corals may avoid bleaching events"

Because most corals grow just centimetres each year, it will be months or even years before it is clear if they can thrive on the turbines. The temperature of the deeper water around them tends to be more stable than it is in shallower areas, so these corals may avoid warm-water bleaching events that strike natural reefs.

If a diverse and healthy reef starts to form, Ørsted plans to expand the project to other turbines. ▮

Corryn Wetzel

THE MEANING OF STONEHENGE

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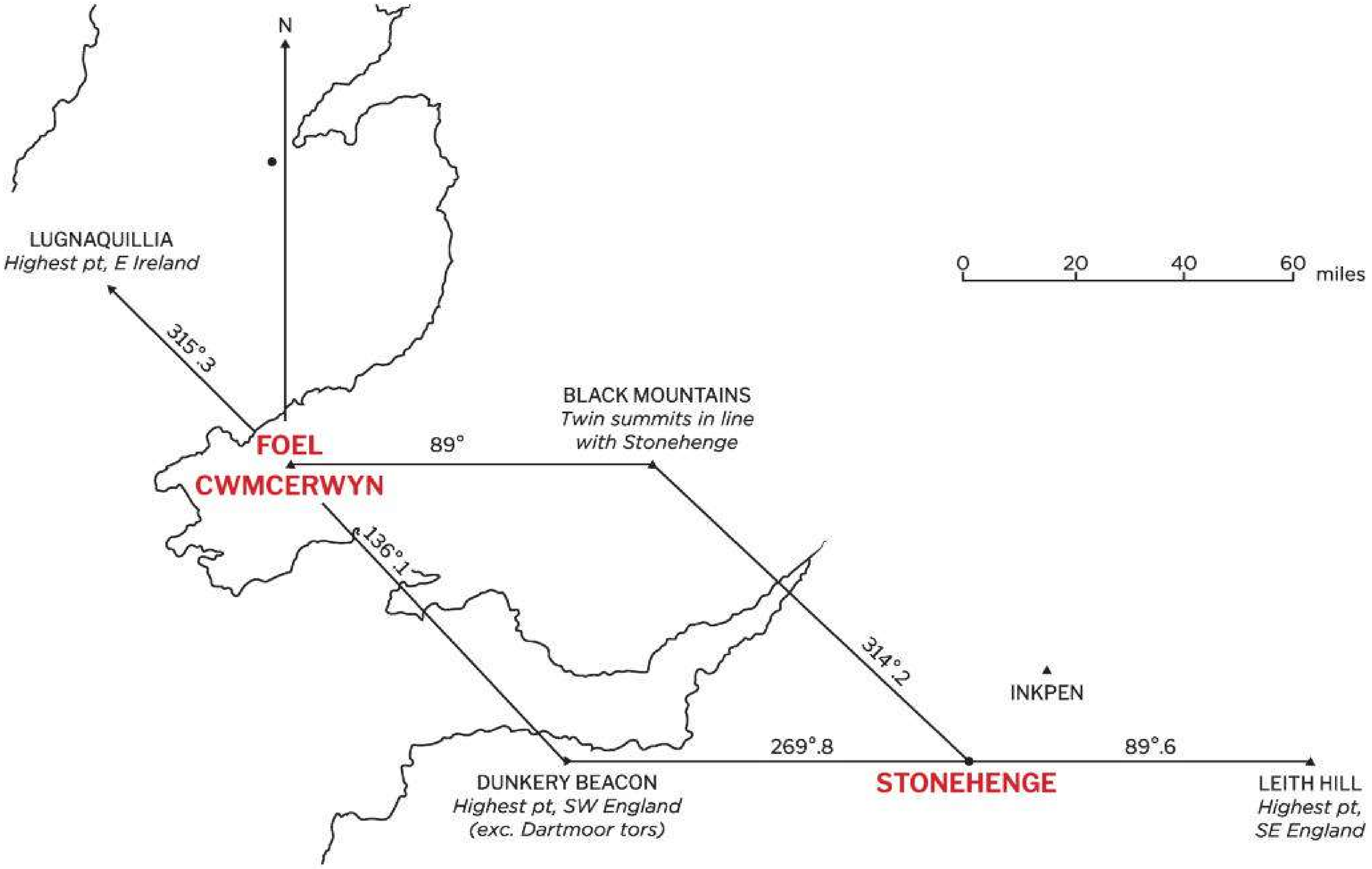

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Wildlife

Monarch butterflies are doing well in North America

DEBRALEE WISEBERG/GETTY IMAGES

DESPITE evidence that monarch butterflies are seeing dramatic losses in overwintering sites in North America, the summer population has been stable for the past 25 years.

"It's one of the most widespread and abundant butterflies in North America right now," says Andy Davis at the University of Georgia.

Around September, the insects (*Danaus plexippus*) leave breeding grounds in the US and Canada and head south to central Mexico and southern California. A survey of their wintering grounds last year found that the eastern population of monarchs have suffered losses of around 70 per cent since the mid-1990s, while those in the west have lost 95 per cent of individuals.

The butterflies' struggle has been attributed to the loss of milkweed in North America – the sole food for monarch caterpillars – and deforestation of wintering habitat.

To discern trends, Davis and his team used more than 135,000 monarch counts done during the summers from 1993 to 2018. The analysis revealed that monarch butterfly numbers are remarkably stable. Across North America, the number increased by an average of 1.36 per cent every summer.

The study authors suspect the butterflies' offspring are making up for winter losses. A female can lay hundreds of eggs each spring, which can enable a dramatic population boom within a single season.

They found small declines in areas where more of the herbicide glyphosate, which kills milkweed, was used (*Global Change Biology*, doi.org/hzb2). **Corryn Wetzel**

Astronomy

Space telescope hit by rock, but all is OK

THE James Webb Space Telescope (JWST) has been struck by a small space rock. A micrometeoroid hit one of its main mirrors, but NASA doesn't expect a significant effect on the observatory's data.

JWST launched at the end of 2021 and reached its permanent orbit in January. Since then, the craft's engineering team has been preparing the telescope's instruments for science observations. The most delicate and finicky part of the observatory is its primary mirror, which is made up of 18 smaller, hexagonal mirrors coated in gold.

The solar system is full of micrometeoroids, most about the size of a grain of dust, so one hitting JWST isn't unexpected. The mirrors were designed to withstand small impacts and were tested for this before the spacecraft launched.

However, the one that hit the telescope in May was larger than anything the NASA researchers tested or simulated on the ground, and because it wasn't part of a meteor shower, nobody predicted it. Had they known it was coming, the telescope's operators would have been able to manoeuvre the craft to avert a direct impact.

"We have had four smaller measurable micrometeoroid strikes that were consistent with expectations and this one more recently that is larger than our degradation predictions assumed," said JWST team member Lee Feinberg at NASA's Goddard Space Flight Center in a statement.

While the impact's effect on the telescope is detectable, it was found that future images won't be degraded too badly. For now, JWST is still performing well above the level required for its planned science observations, including those of the early universe and the very first galaxies. **Leah Crane**

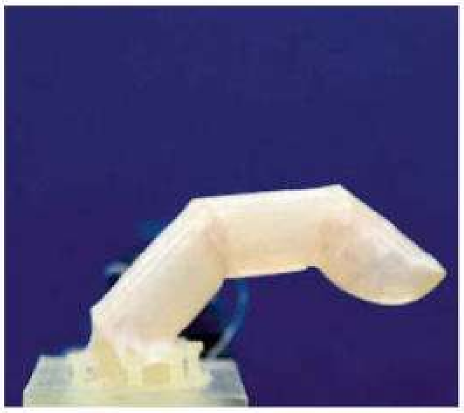
Technology

Human skin used to coat machine digit

ROBOTS can now be covered in living skin grown from our cells to make them look more like us.

As robots increasingly take on roles that involve close personal contact, it is important to make them look more human so we feel comfortable interacting with them, says Shoji Takeuchi at the University of Tokyo in Japan.

At the moment, robots are sometimes coated in silicone rubber to give them a fleshy appearance, but the rubber lacks the texture of human skin, he says.



SHOJI TAKEUCHI/UNIVERSITY OF TOKYO

To make more realistic-looking skin, Takeuchi and his team put a plastic robot finger in a soup of collagen and human skin cells called fibroblasts for three days. The collagen and fibroblasts stuck to the finger and formed a layer similar to the dermis – the second-from-top layer of human skin.

Next, they gently poured other skin cells called keratinocytes onto the finger to recreate the upper layer, called the epidermis.

The resulting 1.5-millimetre-thick skin was able to stretch and contract as the finger bent back and forwards (pictured). As it did this, it wrinkled like normal skin, says Takeuchi. However, the skin began to dry out since it lacked blood vessels to keep it moist (*Matter*, doi.org/hzcx).

In the future, it may be possible to incorporate artificial blood vessels, as well as sweat glands and hair follicles, to make it more realistic, says Takeuchi. **Alice Klein**

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Really brief

4 PM PRODUCTION/SHUTTERSTOCK

Dog friendliness linked to genes

Two mutations in a gene involved in the stress response may help explain why dogs are so friendly. Those with at least one of the changes to the *melanocortin 2 receptor* gene were more likely to look at a human handler or understand the person's instructions (*Scientific Reports*, doi.org/hx95).

Bumpy batteries better in the cold

Lithium-ion batteries with a bumpy positive electrode perform better at -20°C than batteries with a flat electrode because of the way the uneven surface causes charged particles to behave. The design also has a longer working life than standard electrode designs (*ACS Central Science*, doi.org/hx96).

Less plastic now on Australian beaches

The amount of plastic litter on Australia's beaches fell 29 per cent over six years, according to a survey of 183 of the country's beaches. The decline, between 2013 and 2019, reflects local council initiatives, although some places fared substantially better than others (*One Earth*, doi.org/hzbs).

Neuroscience

Control centre for fever is discovered

BRAIN cells that generate fever and other symptoms of sickness have been identified in mice.

Animals tend to respond to being ill in the same way, for example with fever, fatigue, loss of appetite and by seeking warmth. Earlier studies suggest fever helps by increasing body temperature – making it harder for pathogens to survive – while fatigue and loss of appetite link to energy regulation.

To pin down the parts of the brain responsible, Catherine Dulac at Harvard University and her team gave mice molecules that induce effects akin to a genuine illness.

They used sequencing and imaging to determine which neurons were most active in the mice brains during the induced sickness. They suspected that they would be in the hypothalamus, where control of appetite and thermoregulation occurs.

The team found neurons that fit the bill in the hypothalamus's ventral medial preoptic area, which is generally responsible for thermoregulation. These were significantly activated by the induced sickness, in comparison with the brains of mice that hadn't been given the molecules.

To confirm the findings, the team then genetically inhibited these neurons within mice. The altered mice didn't develop a fever when given one of the sickness-producing molecules, while also experiencing a smaller drop in their appetites and not seeking as much warmth. They were still fatigued, however, suggesting that this symptom is regulated elsewhere in the brain (*Nature*, doi.org/hzc5). **Jason Arunn Murugesu**

Microbiology

JONATHAN NACKSTRAND/AFP VIA GETTY IMAGES

Thousands of new viruses discovered in the oceans

THE first global survey of marine RNA viruses has found thousands of new ones, some of which play a key role in locking away carbon.

Between 2009 and 2012, seawater samples were collected from the oceans, including the Arctic (pictured). While identifying DNA-based viruses was the initial aim, Guillermo Domínguez-Huerta at the Ohio State University and his team have now surveyed RNA viruses in the samples.

They identified more than 5000 types, almost all new to science. The team looked at the role some of these RNA viruses play in carbon sequestration. Every day, dead plankton sink to the bottom of the ocean, taking the carbon in their bodies with them, which can be locked up for millions of years. This "carbon pump" stores as much as 12 gigatonnes of carbon annually, about a third of all human-caused carbon dioxide emissions each year.

At least 11 of the new viruses are thought to infect plankton that are important to the carbon pump (*Science*, doi.org/gp99qt). Researchers can't yet put precise numbers on how a given virus accelerates or impedes the pump, but Domínguez-Huerta says viruses might be used one day like "fine knobs" to tune it. **James Dinneen**

Biotechnology

Bacteria help larvae to eat polystyrene

ENZYMES produced by gut bacteria in larvae of the beetle *Zophobas morio* can digest polystyrene. The enzymes could be adapted to degrade plastic in recycling plants.

Christian Rinke at the University of Queensland, Australia, and his team found that the main polystyrene-digesting bacterial species in the larvae, known as superworms, included *Pseudomonas aeruginosa* and species belonging to the *Rhodococcus*, *Corynebacterium* and *Sphingobacterium* groups.

They found that these produced enzymes called hydrolases that degrade the plastic into styrene monomers, which are then broken down inside bacterial cells.

In lab tests, the team noted that superworms can survive on just polystyrene and even gain a small amount of weight, suggesting they can gain energy from eating it.

The researchers want to develop a plastic recycling application, focusing on a system that mimics the mechanical degradation by the larvae, followed by further degradation by bacterial enzymes to produce chemical compounds of higher value, such as bioplastics (*Microbial Genomics*, doi.org/gp99rv). **Carissa Wong**

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Comment

Healing encounters

Social media's rise means policies requiring anonymity in organ donation are obsolete, say **Nicholas Murphy** and **Charles Weijer**

SIMONE ROTELLA

IN JUNE 2012, Canadian teen Tyler Schwering died after an accident. Knowing it is what he would have wanted, Tyler's mother, Kim LeBlanc, consented to organ donation on his behalf. That decision saved the life of Dave Allingham, who received Tyler's heart the next day. A year later, after finding one another with the help of social media, LeBlanc and Allingham met. Both say the experience was life-changing.

"Seeing what has come of something horrible has given me peace," says LeBlanc. Allingham, now free of his heart condition, welcomed the chance to express his gratitude. "I cherish the gift I've been given," he says. "Tyler's legacy is alive and well."

Look around Facebook and it isn't hard to find groups dedicated to connecting the families of deceased donors with the recipients of their loved one's organs. Discussion boards feature pleas for information from those involved, desperate to know more about the people on the other side of their donation story.

Groups like these are a reaction to policies mandating anonymity in deceased organ donation. Frustrated by this, people are taking matters into their own hands. By turning to social media, families of the deceased and organ recipients seek to reap the benefits that can arise when the two sides get to know each other. Yet, they are also unwittingly exposing themselves to potential harm should relationships go awry. It is time for policy-makers to address the realities of the social media age by relaxing restrictions and developing policies that will promote safe encounters for those who want them.

Since its advent in the 1950s, organ transplantation has become the treatment of choice for various diseases that eventually lead to organ failure. Globally, tens of thousands of people who die donate their organs to other people every year. Yet, with few exceptions – such as Israel and some programmes in the US – organ donation organisations can't disclose identities, even when both sides want to meet.

The decades-old regime of mandated anonymity arose in response to concerns about the risks of identity disclosure. For example, it was feared that getting to know an organ recipient could complicate the grieving process for donor families, or lead to feelings of indebtedness in recipients.

Times have changed. These policies should be recognised for what they are: unfair restrictions on the autonomy of competent adults. Although there are risks to direct contact, evidence from places in which it is allowed shows there can be mutual and profound benefits. Getting to know a recipient can allow donor family members like LeBlanc to find meaning in loss and see the legacy of their loved one's gift. For recipients like Allingham, the ability to express gratitude can be transformative. Denying people these benefits is paternalistic and wrong.

Some places have recognised this – though most have not. As a result, people turn to platforms like Facebook to make contact. This exposes how mandated anonymity isn't just unfair, it is also fast becoming obsolete. The reality is that barriers are increasingly bypassed through the Wild West of social media, but this means there is then no support available for those involved.

Organ donation organisations should face up to the realities of the social media age by developing responsible policy to facilitate direct contact between donor families and organ recipients. A balanced approach will help to protect anonymity for those who want it and allow safe contact when both sides wish it. There is no stopping mutually interested parties from meeting. The question now is, how do we manage it responsibly? ▮

Nicholas Murphy is a postdoctoral fellow at Western University in Ontario, Canada. Charles Weijer is a professor of medicine and philosophy at Western University.

No planet B

The biodiversity diet I thought my Mediterranean-style diet was helping the planet, but while it has reduced my carbon footprint, it is harming Earth's biodiversity, finds **Graham Lawton**

Graham Lawton is a staff writer at *New Scientist* and author of *Mustn't Grumble: The surprising science of everyday ailments*. You can follow him @grahamlawton

I HAVE been writing a lot about food recently, from the perspective of both human and planetary health and longevity. Happily, those two goals are often in harmony – in a nutshell, eat less meat and other animal products – which gives me a healthy inner glow topped with a green halo. I stopped eating the flesh of mammals and birds a few years ago and largely stick to a Mediterranean-style diet, which involves eating more fruit, vegetables and whole grains.

But as I found out recently to my dismay, I may have to relinquish that halo. Like many environmentally conscious eaters, I have only been looking at one side of the menu: climate change. My dietary choices have almost certainly reduced my carbon footprint. But what about biodiversity? On that front, my diet may need a radical rethink.

As has been well documented, the industrialised food system is one of the principal drivers of climate change. It takes land to grow crops and rear animals, and fields and pasture are often carbon sources rather than carbon sinks. Agricultural machinery belches out greenhouse gases, as do cows and other ruminants. The staggering quantities of food that are wasted at every stage from farm to fork mean that much of this climate damage doesn't even contribute to human well-being.

This is what most green consumers focus on when switching to a less impactful diet, usually by eating more plants, cutting down on waste and buying locally produced food. All are commendable and meaningful choices. But there is more to life than climate change. Biodiversity loss is as much of a threat to planetary habitability, but up to now has barely figured in our dietary calculations.

Which is why a recent analysis published in the journal *PNAS* deserves much wider attention. In it, a team at the University of Maryland's National Socio-Environmental Synthesis Center (SESYNC) makes a start on introducing biodiversity into the conversation. The researchers analysed the biodiversity impact of five diets widely consumed in the US, from the red meat of the country's traditional fare to the distinctly green Planetary Health Diet recommended by *The Lancet* in 2019. The other regimes were healthy US-style, healthy Mediterranean-style and healthy vegetarian. They also considered the impact of reducing food waste by 50 per cent on all five diets.

> **"There is little doubt that eating well for the planet requires sacrifices I am currently not prepared to make"**

For each of these 10 scenarios, the team modelled how adoption by everyone in the US would alter land use, and how that would change the extinction risk of land animals and plants worldwide.

To no one's great surprise, the meat-heavy US diet, rich in processed food, would be catastrophic, condemning around 200 species to extinction, 40 per cent of them outside the US. These irreversible losses – mostly of plants – would be driven in the main by the conversion of natural habitats to pastureland. A 50 per cent reduction in food waste would still doom more than 175 species to extinction.

Again, to no great surprise, the diets least harmful to biodiversity are the vegetarian and planetary health ones with reduction in food waste. But neither is squeaky green: both still commit around 100 species, again mostly plants, to extinction. Much of this damage is caused by imported fruits and commodity crops grown in biodiversity hotspots, especially Ecuador, Colombia, Mexico and Indonesia.

Now here's the sickener. The worst diet of all is the Mediterranean-style one, which, if universally adopted across the US, would cause 240 extinctions, mostly outside the country's borders. The main driver of these would be increased demand for seafood, which the authors assume would have to be met by aquaculture (probably correct, given the state of wild fish stocks), requiring natural land to be given over to grain to feed the fish. Reducing food waste would cut this carnage a bit, but still leaves the Mediterranean diet worse than the meat-heavy US one with current levels of food waste.

In my defence, the Mediterranean diet in the analysis includes meat, which I don't eat, and quite a bit of dairy, which I limit. But the result leaves little doubt that eating well for the planet requires sacrifices that I am currently not prepared to make. And even then, it can't be done. To participate in the agro-industrial complex is to be complicit in the extinction of dozens of species.

There is, thankfully, a genuine alternative on the horizon: cultured meat and precision fermentation. Both are in their infancy, but, once mature, promise to meet our demand for meat, dairy and fish while leaving space for nature. Environmentalists may be wary of such "unnatural" methods, but anyone who cares about the environment should be licking their lips at the prospect. ▮

Graham's week

What I'm reading

Empire of Pain: The secret history of the Sackler dynasty *by Patrick Radden Keefe. A shocking and gripping account of one family's central role in the US opioid epidemic.*

What I'm watching

I have been re-bingeing Detectorists.

What I'm working on

When this comes out, I will be glued to my screen watching the American Society of Nutrition's annual meeting. More food writing beckons.

This column appears monthly. Up next week: Annalee Newitz

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Science of the Incas: Peru

A unique anthropology and archaeology experience

Immerse yourself in the Inca civilisation's most important archaeological sites, science and history while exploring Peru's beautiful Sacred Valley. Of course, you will visit Machu Picchu, as well as get to the heart of how Hiram Bingham "discovered" it and several other Inca sites just over 100 years ago.

But the story of the Incas is so much more than just Machu Picchu. They arranged their religious sites, or huacas, along a system of astronomically and calendrically informed lines, called ceques, centred on the ancient city of Cusco, a further highlight of this trip. As the tour will explore, this "calendar on the ground" affected the location of Inca towns, their ceremonies, the social interactions of their elite groups and their highly advanced architecture.

This unique expedition will be accompanied throughout by anthropologist, explorer and Emmy award-winning filmmaker Peter Getzels, and further benefit from the expertise of Jean-Jacques Decoster, professor of anthropology at the Universidad Nacional San Antonio Abad in Cusco. Learn how the Incas developed a complex society and used their extensive grasp of science and technology to expand rapidly, and marvel at their mastery of stone-cutting, astronomy and mathematics to create buildings for living and worshipping in and systems of irrigation and aqueducts to precisely control water for high-altitude farming on steep slopes.

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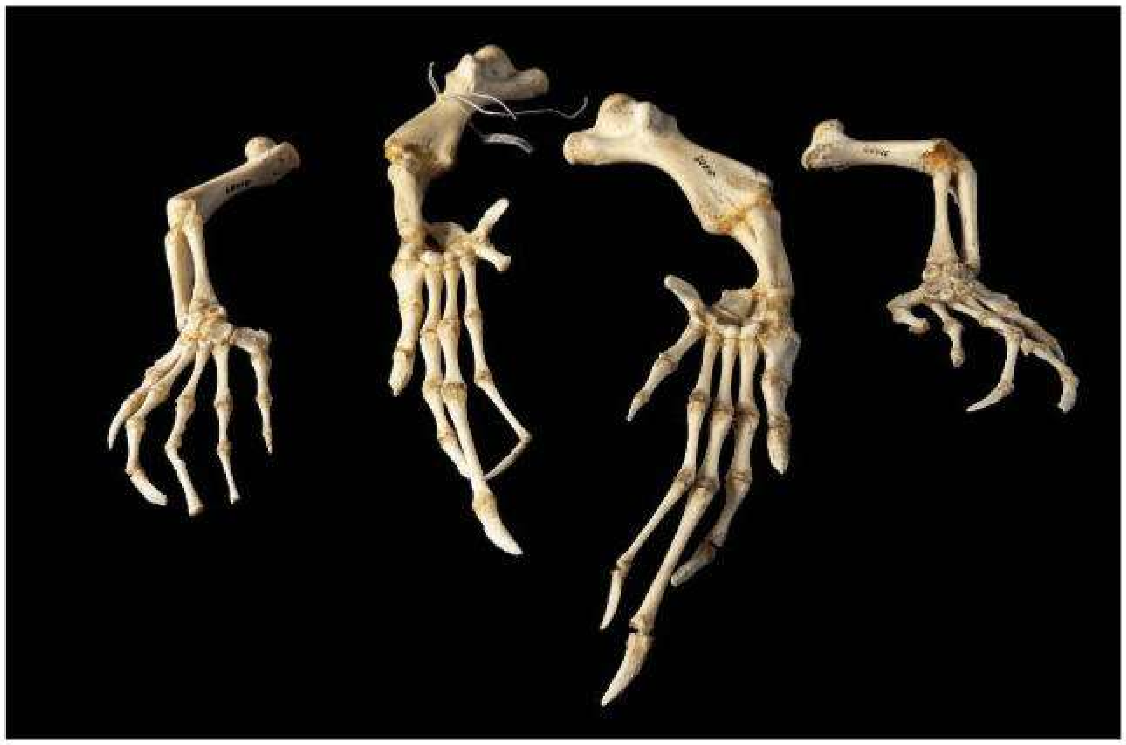

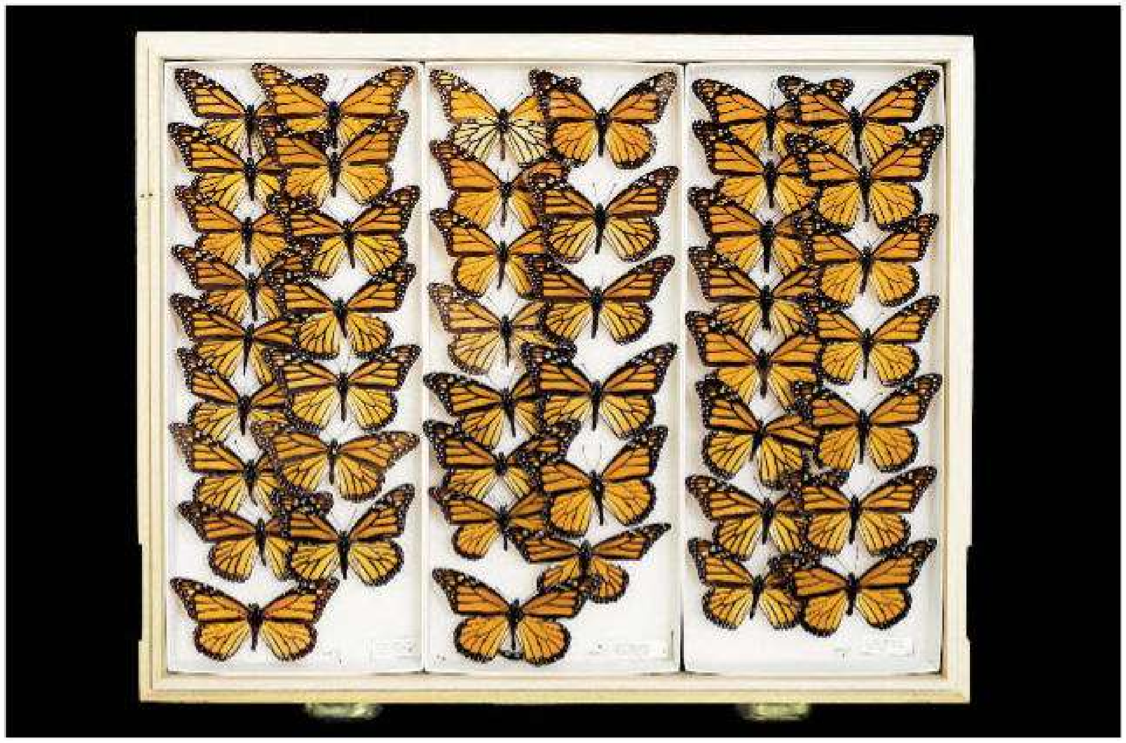

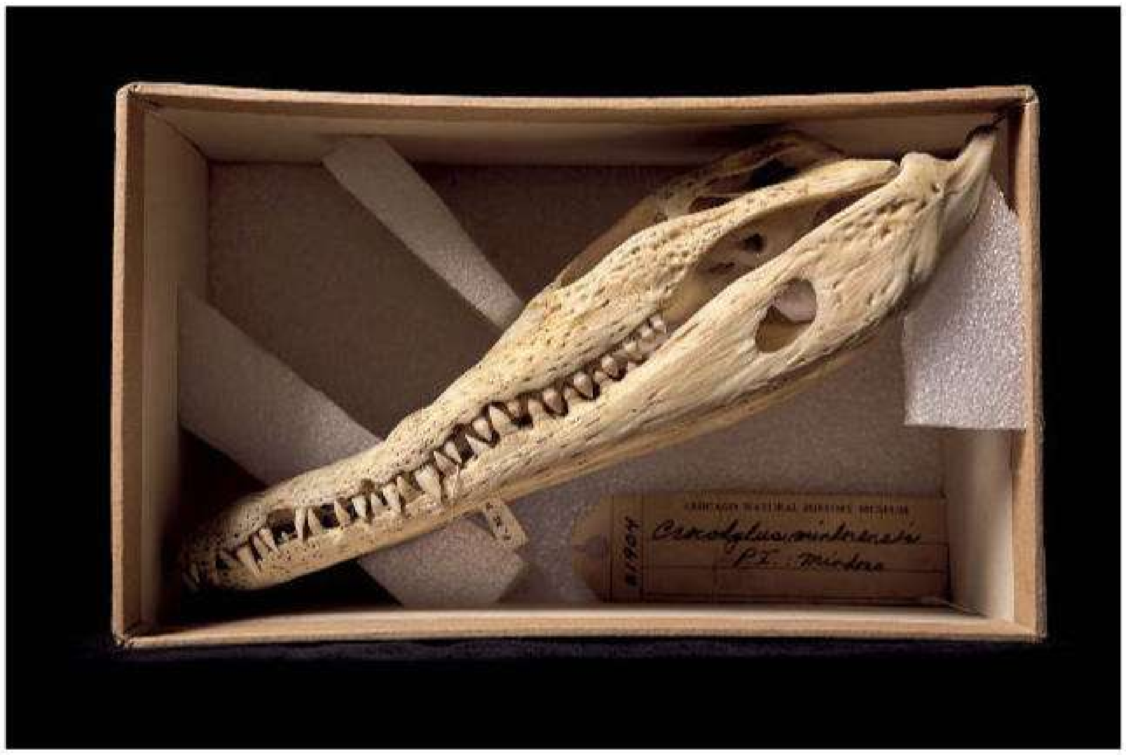

Life on the brink

Photographer Marc Schlossman

THESE fascinating shots of animal and plant specimens from the Field Museum in Chicago, Illinois, taken by nature photographer Marc Schlossman, illustrate the fleeting delicacy of life – and its resilience.

They are taken from Schlossman's new photography book, *Extinction*, which calls attention to the main culprits of biodiversity loss – such as climate change and habitat destruction – through the Field Museum's private collections of extinct and endangered species.

Clockwise from the top left corner, the images show: leaves from a big-leaf mahogany tree (considered vulnerable, according to the IUCN Red List); the tail feathers of a kakapo bird (critically endangered); bones of a hawksbill sea turtle (critically endangered); monarch butterflies (of least concern, according to the IUCN, but Schlossman says recent findings show there has been a significant decline in species numbers); the skull of a Philippine crocodile (critically endangered); a rusty patched bumblebee (critically endangered); passenger pigeons (extinct); bones of Atlantic halibut (endangered); and a Santa Catarina leaf frog (near threatened).

Schlossman hopes people will engage with biodiversity loss through the stories of species both past and present, but points out it doesn't always have to be a gloomy affair. "The thing that was so interesting about photographing this list of species was to highlight the conservation successes – species that have been brought back from the brink of extinction," he says.

Extinction, published by Ammonite Press, is out now. ▮

Gege Li

Editor's pick

Glimmer of hope in Australia on climate

28 May, p 9

From Geoff Harding, Sydney, Australia

Finally, some positive news from Australia, after 10 years of climate wars that have led to the country being called a climate laggard.

That said, while the newly elected Labor party has set a respectable emissions target – at 43 per cent below 2005 levels by 2030 – it is inadequate to keep global warming at around 1.5°C. Furthermore, the economy's reliance on coal exports may confound efforts to go further than this in the immediate future.

However, pressure exerted internally by the climate-ambitious Greens party and independents, along with international pressure from the COP27 climate summit in November, will hopefully result in a more ambitious target within the next three years.

Is nuclear power the answer to climate crisis?

28 May, p 38

From Ron Barnes, King's Lynn, Norfolk, UK

It is a shame that nuclear power generation is a spin-off from bomb production. That, and some unfortunate accidents, have given it a bad public image. This is hardly justified in terms of the number of people actually killed and injured by the industry.

Nevertheless, I am surprised that thorium-based nuclear reactors haven't been developed for power generation. Thorium is more plentiful and cheaper. It also largely avoids the weapons issue and could potentially make for safer reactors than uranium.

From Henry Preston, London, UK

In your look at the debate on nuclear energy and its role in the shift from fossil fuels, you state that "France was 4 percentage points behind its target for renewable generation in 2020, while... Germany's nuclear phase-out induced investment in wind and solar, and the country was 1 per cent ahead of its 2020 target."

That isn't the whole story. Despite this, France emits half the carbon dioxide of Germany, thanks to having over 70 per cent of its grid electricity supplied by nuclear power plants that were built after the 1973 oil crisis.

Splitting the atom produces far more energy than any other power source harnessed by humans. This energy density is why it has the least land and resource impact, the lowest carbon emissions and lowest volumes of harmful waste.

From Ulrich Seydel, Melbourne, Australia

There is a common problem with the debate about renewable energy. People tend to talk about electricity production, when they should talk about primary energy consumption. Transport, heating and manufacturing all need to be decarbonised as well.

For example, Germany only meets about 15 per cent of its total energy consumption with renewables. Therefore, I think it is questionable whether Germany and other countries will be able to produce all their energy by renewable means.

From Barry Cash, Bristol, UK

The estuary of the river Severn in the UK has the second highest rise and fall of tide in the world. The last proposal to generate electricity from it failed because it would have destroyed mudflats on which many birds depend. Now, Rod Rainey, visiting professor of engineering at the University of Southampton, UK, has designed a tidal power system that would be able to generate renewable energy while allowing preservation of the mudflats.

Not only would this be cheaper than the Hinkley Point C nuclear plant, it would be cheaper than an equivalent gas-fired station.

Traditional crops could help plug wheat shortfall

28 May, p 18

From Judith Appleton, Hebden Bridge, West Yorkshire, UK

While the Ukrainian wheat aspect of the current food crisis is in the news, another *New Scientist* article deserves a second look, not least as a reminder that food-aid policies have contributed to some of our current global problems.

Morton Satin's piece "Bread without wheat" (28 April 1988, p 56) gave an excellent overview of the way that some low-income countries have been pressed into importing wheat as aid, replacing demand for traditional crops and skewing their rural economies.

Wheat for use in bread was a big incentive, providing urban consumers with a filling option without the time and drudgery needed to process traditional crops. But those crops can provide flour for bread too, requiring only a little inventiveness in order to replace the vital gluten.

Sometimes, solo work is just what science needs

14 May, p 28

From Adrian Bowyer, Foxham, Wiltshire, UK

I was interested to read Chanda Prescod-Weinstein's column on the importance of teams in science when compared with isolated achievers. I am known – albeit slightly – for two scientific and engineering projects: the Bowyer-Watson algorithm in computational geometry and the self-replicating 3D printer, RepRap.

Despite its name, I worked on the Bowyer-Watson algorithm alone. Though David Watson developed it at the same time, neither of us knew about the other's work until it was complete. The self-replicating printer, on the other hand, was developed by a team I led that was so large I didn't even know everyone's names.

Collaboration is nice and so it tends to be lauded. But sometimes people need isolation in order to think hard and achieve something significant by themselves.

On the battle against misinformation

28 May, p 28

From Robert Peck, York, UK

In trying to plot a course between total censorship and information anarchy, Annalee Newitz doesn't assuage any of the dangers of censorship. While ideally one could just magic away untrue content, in reality, the only way to judge truth without the use of free speech and open debate is by appointing someone to decree it.

This emboldens many of the world's worst leaders to enforce their own interpretations of the truth. When considering if global censorship might be an appetising prospect, it is crucial to ponder whether one's answer would still be the same under all the governmental regimes that exist around the world, and also those that may exist in the future.

For the record

- **Wood burning costs the EU and UK €13 billion a year in health-related costs and is responsible for 48 per cent of health costs from air pollution due to fossil fuels and wood burned in homes for heating or cooking (9 April, p 22).**
- **Monkeypox, despite its name, usually spreads among animals such as rodents in parts of Africa (28 May, p 8).**

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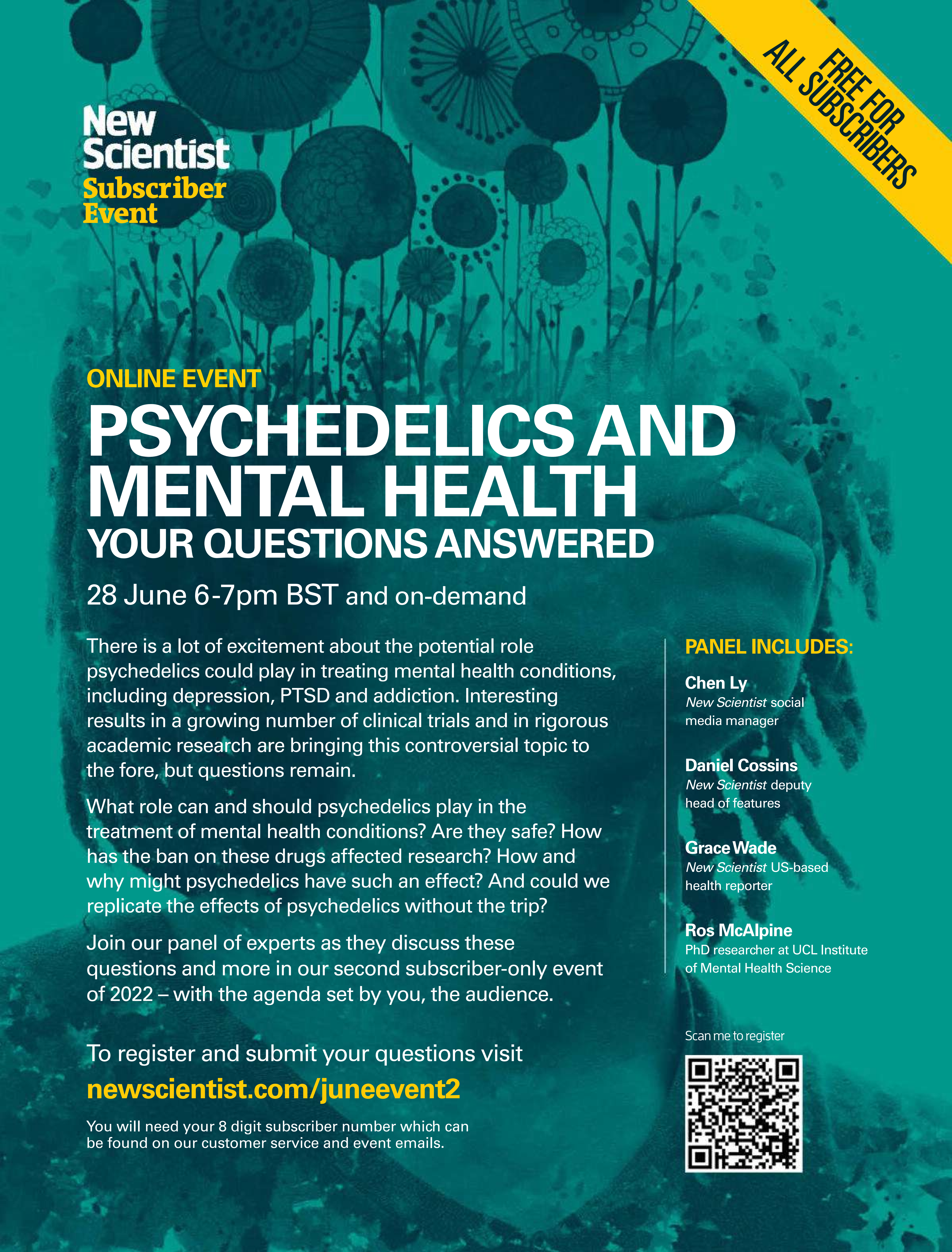

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There is a lot of excitement about the potential role psychedelics could play in treating mental health conditions, including depression, PTSD and addiction. Interesting results in a growing number of clinical trials and in rigorous academic research are bringing this controversial topic to the fore, but questions remain.

What role can and should psychedelics play in the treatment of mental health conditions? Are they safe? How has the ban on these drugs affected research? How and why might psychedelics have such an effect? And could we replicate the effects of psychedelics without the trip?

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Making sense of the world

Our neat ways of measuring feel like they have always existed. A romp through history shows it is much messier than that, finds **Chris Stokel-Walker**

SCIENCE HISTORY IMAGES/ALAMY

Ancient Egypt's systems of measurement were based on the human body

Book

Beyond Measure

James Vincent

Faber

WE TAKE the certainty of measurements for granted, but their story is as complicated and changeable as any other part of human culture. Journalist James Vincent makes this clear in his new book, which explores the history of calculating things.

Beyond Measure is a pacy romp through time and space, moving from ancient Egyptians with their body-centric measuring systems to present-day scientists seeking to standardise measurement. But it isn't just the stories of the rule-makers: measurement has been as much about dispute as diktat, and Vincent explains how important the standardisation of weights and measures was and is for all of us.

He starts with familiar stories about how measurement has changed – from decimalisation to the trouble with Le Grand K, the 133-year-old kilogram cylinder in a vault within the International Bureau of Weights and Measures in Sèvres, France, which had a nasty habit of losing weight.

Then we learn about small objects with a big impact, such as the strickle, a stick used to smooth off the top of a grain container to create a reliable, fair measure. But we also get a bird's eye view: a chapter on why the US has its famous grid system of roads is particularly enlightening.

Vincent tells a story of a world constantly in flux, of tested measurements we assumed had been around forever popping up more recently than we thought, while other superannuated means of measuring just stick around.

We also meet traditionalists, holding out against what is often seen as the natural evolution of weights and measures. Vincent goes on a guerrilla mission with the Active Resistance to Metrication (ARM), a British campaign group hoping to retain imperial units, as they alter road signs in Thaxted, south-east England.

ARM may seem extreme, but wars have been fought over how we measure things. For example, the book highlights how conflict over measurements was a key part of the French Revolution.

Yet Vincent also shows that the more things change, the more they stay the same. We think we are better than our predecessors at accounting for and enforcing the reliability of a metre, kilogram or day. But as Vincent writes, we frequently betray that claim to precision: "We explain to a friend that the next pub is just a five-minute bike ride away, or that the beach is just an hour's drive." More recently, we have estimated walks in podcast lengths, or flights in the number of movies crammed in.

So why do we keep hold of such personal measures? It is here that Vincent is at his most lucid – and where the book's point becomes clear. "They transfer information from an objective realm of distance to a subjective one of experience," he writes. "They allow us to contextualise the world around us, and make sense of it." ▮

Chris Stokel-Walker is a technology journalist based in Newcastle, UK

Defying the ravages of age

Book

Jellyfish Age Backwards

Nicklas Brendborg

Little, Brown

FROM the *Epic of Gilgamesh* to alchemists' quest to find the fabled philosopher's stone, stories of perilous, yet ultimately fruitless, pursuits of immortality are ubiquitous. Even today, humanity seems determined to unlock the secrets of a long life. But now we look to science, not legend.

In *Jellyfish Age Backwards*, molecular biologist Nicklas Brendborg takes us on a whistle-stop tour of the science of ageing. We begin with a visit to a few of the many natural wonders that defy our ideas of ageing. These include the 400-year-old shark that roams the Greenland Sea and the species of tiny jellyfish, *Turritopsis dohrnii*, that can regress from adulthood back to infancy when stressed – fulfilling the book's title.

Brendborg details the scientific gains in this field over recent decades. There is a biotech executive who successfully edited her own DNA in an attempt to prolong healthy cell function in 2015, and just this year, researchers managed to turn back the biological clock on human skin cells by exposing them to specialist molecules dubbed "Yamanaka factors".

Exciting stuff, but anti-ageing science is in its infancy, with most discoveries Brendborg cites yet to be trialled in humans. Yet he navigates this bustling discipline with graceful clarity, dispelling common myths along the way – for example, intermittent fasting may not help you live longer.

While immortality may be too tall an order, Brendborg believes medical science will triumph, and a generation will be born that is "the last to be ravaged by ageing". ▮ Chen Ly

Join Agnijo Banerjee on his quest for unfathomably large numbers at New Scientist Live on 8 October
newscientistlive.com

How big can they get?

Explore googology in a brilliant new guide and learn about the esoteric world of enormous numbers, says **Timothy Revell**

Book

The Biggest Number in the World
David Darling and Agnijo Banerjee
Oneworld

DR EVIL (aka Adam Elga) walked up to a blackboard in front of a packed auditorium at the Massachusetts Institute of Technology and wrote a single 1. It was a slow but tactical start to the 2007 Big Number Duel, an event described on its posters as: "Two competitors. One chalkboard. Largest integer wins."

The Mexican Multiplier (aka Agustin Rayo) wasn't happy with such a slow start, so he filled in the blackboard with 1s. Dr Evil countered by turning almost every 1 into the factorial sign "!". This clever mathematics trick soon transformed the figures on the board into impenetrably large numbers, containing more digits than there are particles in the universe. The pair had moved into the world of googology – the study of extremely large numbers.

Googology is a mind-boggling subject, and the topic of a wonderful new book, *The Biggest Number in the World: A journey to the edge of mathematics* by David Darling and Agnijo Banerjee. The co-authors met when Banerjee was a teenage mathematics prodigy and Darling, an eminent science writer, became his tutor. Banerjee went on to get a perfect score at the International Mathematical Olympiad, one of only two out of 594 contestants from more than 100 countries to do so.

The Biggest Number in the World starts out by tackling such "normal" big numbers as the number of stars in the observable universe (70 billion trillion) or the number of ways to shuffle a pack of playing cards (8.0658×10^{67}). But then it quickly introduces the tools needed to write far larger values.

> "If you love journeying into imagined mathematical worlds, then you'll find this book pure escapism"

Numbers are like interstellar travel, write the duo. If spacecraft are too slow – and they are – it could take us tens of thousands of years to reach other solar systems. The same is true when writing massive numbers, so we need the mathematical equivalent of better propulsion methods, such as Knuth's up-arrow notation.

This notation is named after computer scientist Donald Knuth, and emerges from a simple pattern. Recall that multiplication is simply repeated addition ($5 \times 3 = 5 + 5 + 5$) and exponentiation is just repeated multiplication ($5^3 = 5 \times 5 \times 5$). Up-arrow notation uses a single up arrow to mean exponentiation, so that $5 \uparrow 3 = 5^3$. Two arrows then mean repeated exponentiation $5 \uparrow\uparrow 3 = 5 \uparrow (5 \uparrow 5) = 5^{5^5}$.

This pattern continues, with each new arrow meaning the steps before should be repeated, resulting swiftly in immense numerical power. The number $2 \uparrow\uparrow\uparrow\uparrow 4$, for example, is so large it is "beyond the capacity of the universe to display in digital decimal form", write the authors.

If you are someone who needs real-world applications to get excited about mathematics, this probably isn't the book for you. But if you love journeying into imagined mathematical worlds and simply exploring, then it is pure, unadulterated escapism.

In different hands, the book could have been too jargon-packed to hold the attention of the average reader, but Darling and Banerjee have done a brilliant job mixing big ideas and analogies with the tools needed to understand up arrows and other approaches to notation, each more powerful than the last.

Darling and Banerjee don't shy away from their book's title, and eventually deliver a number so large it is very likely to earn the accolade of biggest number in the world. This number is so huge that when the Mexican Multiplier wrote it on the blackboard in the Big Number Duel, it was considered to be a knockout blow. ■

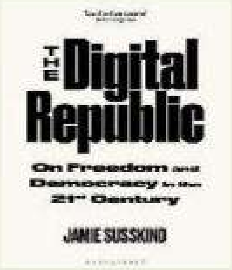
Reaching far along the number line requires mathematical booster technology

GRANT FAINT/GETTY IMAGES

Don't miss

Watch

The Umbrella Academy is back for a third season, in which the adopted-sibling superheroes meet their less dysfunctional counterparts in an alternative reality. Available to watch on Netflix from 22 June.



Read

The Digital Republic is possible, says Jamie Susskind. He explains how – with proper governance and new institutions, rights and regulators – freedom and democracy can survive despite powerful digital technologies. Buy from 23 June.

Play

Deliver Us the Moon sends you to Earth's moon as humanity's last astronaut, on an open-ended, do-or-die mission to find a missing energy source and save our world. Available on PlayStation 4, Xbox One and PC from 23 June.

WIRED PRODUCTIONS/KEOKEN INTERACTIVE

Creativity and chaos

While David Cronenberg's new movie intrigues, it is a missed opportunity to create compelling, transgressive sci-fi, says **Davide Abbatescianni**

Film

Crimes of the Future

David Cronenberg

Now playing in US cinemas; UK dates pending

NIKOS NIKOLOPOULOS/NEON

Viggo Mortensen plays an artist who can grow new organs

SURGERY is the new sex – or at least it is in the world envisioned by David Cronenberg in his latest outing, *Crimes of the Future,* which premiered at the Cannes Film Festival last month.

The story takes place in an unsettling future, where humans have adapted to an environment they have polluted for decades – or is it centuries, perhaps millennia? In this dystopia, body modification represents a form of entertainment and offers new scientific objects to analyse and dissect.

The movie opens with a shot of a boy (Sozos Sotiris) standing by the sea. He is scolded by his mother (Lihi Kornowski), who forbids him from eating "anything he finds". That night, the mother discovers her son crunching on a plastic bucket and she chokes him with a pillow, leaving the corpse for his father (Scott Speedman) to find.

We soon meet two other characters – Saul Tenser (Viggo Mortensen), an ageing celebrity performance artist who can grow unidentified organs, and his loyal partner Caprice (Léa Seydoux). These storylines slowly converge, promising to reveal something crucial about our species' future. Any more details about these characters would probably warrant a spoiler warning.

Despite this intriguing opening, two large flaws prevent the film from developing into a credible sci-fi tale with Cronenberg's usual transgressive edge. The first lies in its internal logic. Although the attempt to create a future where our bodies take centre stage and regulate power dynamics and social interactions is compelling, Cronenberg breaks many of the laws that appear to govern it.

The widespread use of surgery is justified by the fact that humans can no longer feel pain. Yet many characters are shown to experience sexual pleasure – or at least some kind of enjoyment – through their surgery. So, what do they actually feel? Do some people experience sensation, while others have lost the ability? Why? These important questions are left hanging.

We are also shown people performing all kinds of advanced surgery – sealing shut eyes and mouths, extracting and tattooing organs, cutting deep into every inch of their body and more. Most of this activity isn't visible after a few minutes or hours, but some people do display marks. It seems that human bodies have become immune to infection. However, people aren't immortal and can be killed – an old-school drill to the temple proves highly effective, for example.

While Cronenberg is evidently crafting a work of science fiction, this lack of explanation fuels a sense of incoherence. Setting a few, clear rules governing this world would have increased the potential to make it a believable place, no matter how weird and unlikely it might appear.

> "Many characters are shown to experience some kind of sexual pleasure through their surgery"

The second flaw is the acting, notably Kristen Stewart's. She plays Timlin, a creepy assistant who works with an investigator named Wippet (Don McKellar) at a clandestine branch of government called the National Organ Registry, which classifies new organs.

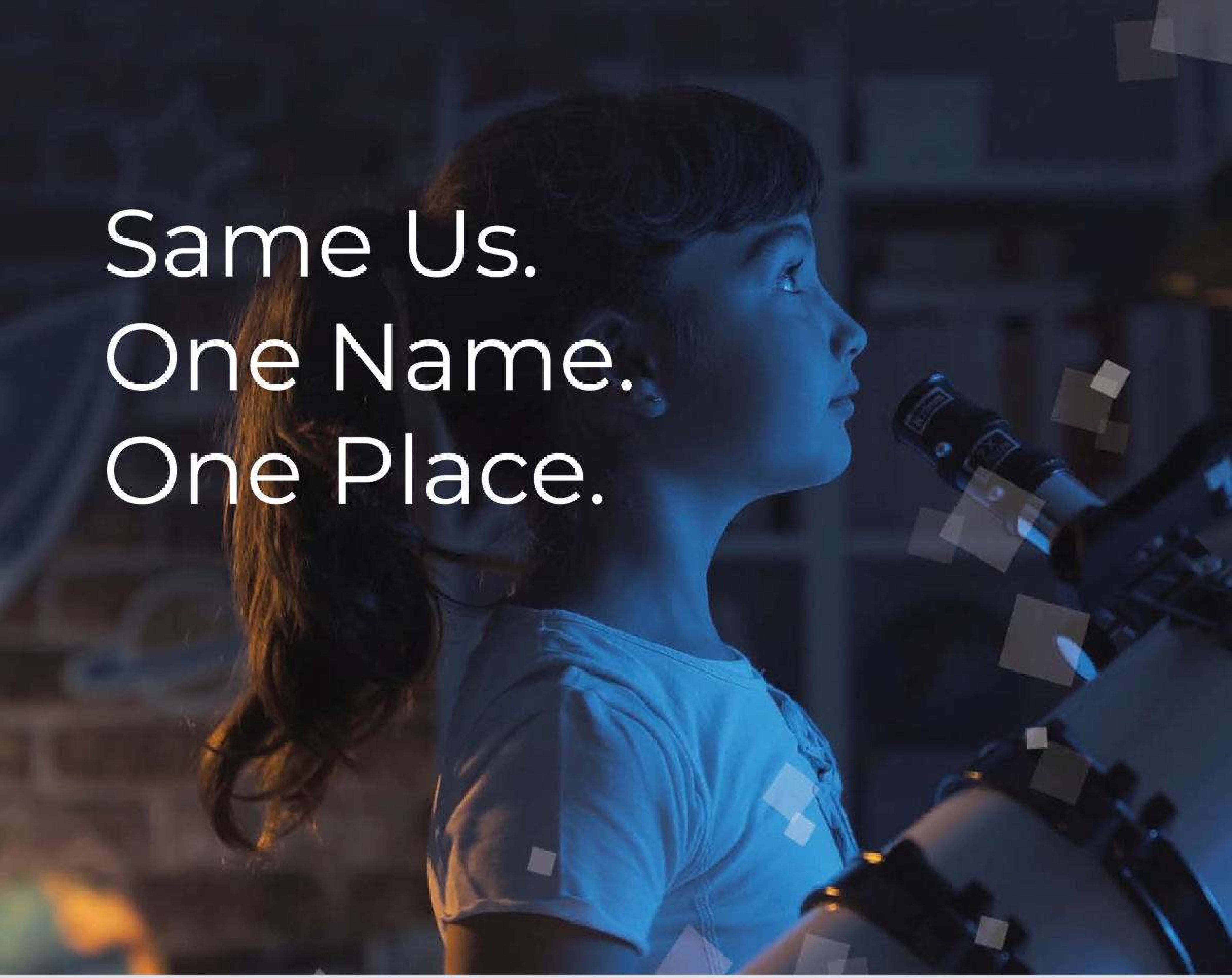
Stewart imbues her role with the same hesitancy she showed as Princess Diana in *Spencer* – though without the upper-class English accent – and this ensures that her character is at the centre of several embarrassing moments. From her first appearance, we struggle to believe that she is any sort of public official, or that she has developed a morbid fascination with Tenser and Caprice, and their disturbing practices.

While not exactly bad, the acting seems to be undermined by the dark humour running through the film. While it is good to see that Cronenberg isn't taking himself too seriously, the humour displayed here doesn't emerge organically. Instead, it makes the picture seem more chaotic, as the sometimes nonsensical dialogue destroys any serious emotional development, reducing the characters to caricatures.

These imperfections render the director's attempt to create a transgressive discourse on human evolution almost irrelevant. All in all, *Crimes of the Future* feels like a missed opportunity. It had some of the initial ingredients to make an unusual sci-fi story, but it failed to grip me, and led only towards a predictable ending.

And yet, the complexity of this work and its radical artistic choices are guaranteed to divide audiences. On those ground alone, we are sure to hear more about it. ▮

Davide Abbatescianni is a film critic based in Rome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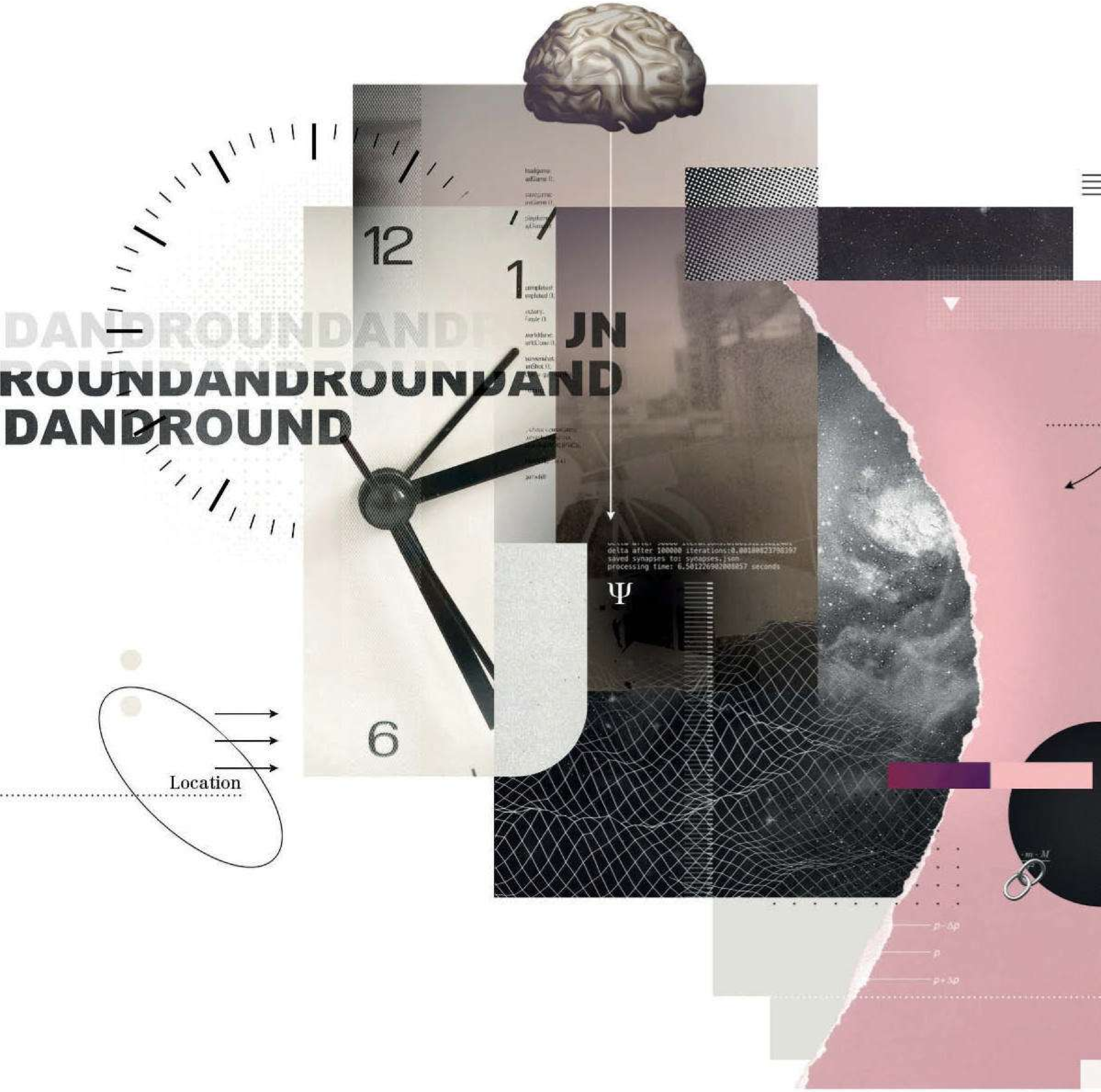
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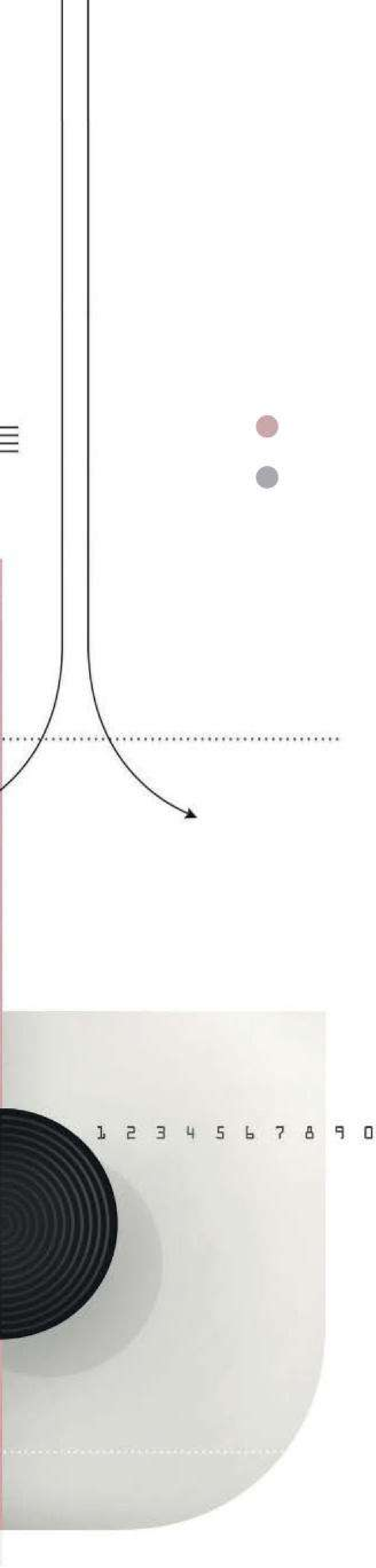
SKIZZOMAT

MYSTERIES OF THE FOURTH DIMENSION

IT IS WOVEN INTO THE FABRIC OF THE UNIVERSE. IT EXERTS A PROFOUND INFLUENCE ON OUR LIVES. YET WE KNOW PRECIOUS LITTLE ABOUT ITS TRUE NATURE AND THE STRANGE WAYS IT AFFECTS US. HERE, NEW SCIENTIST INVESTIGATES NINE OF THE BIGGEST QUESTIONS ABOUT TIME

00:01 WHAT IS TIME?

WE ARE BORN; we live; at some point, we die. The notion that our existence is limited by time is fundamental to human experience. We can't fight it – and truth be told, we don't know what we are fighting against. Time is a universal whose nature we all – and physicists especially – fail to grasp. But why is time so problematic? "If we had a really good answer to that question," says Astrid Eichhorn, a theoretical physicist at the University of Southern Denmark in Odense, "then it wouldn't be so problematic."

On a certain level, time is simple: it is what stops everything happening at once. That might seem flippant, but it is at least something people can agree on. "The causal order of things is really what time is all about," says Eichhorn.

Viewed this way, the existence of time can be interpreted as a necessary precondition for the sort of universe where things lead to other things, among them intelligent life that can ask questions, such as "what is time?". Beyond that, time's essence is mysterious. For instance, why can things only influence other things in one direction in time, but in multiple directions in the three dimensions of space (see "Why does time only go one way?", page 40)?

Most physical theories, from Isaac Newton's laws of motion to quantum mechanics, skirt such questions. In these theories, time is an "independent variable" against which other things change, but which can't be changed by anything else. In that sense, time exists outside physics, like the beat of a metronome outside the universe to which everything inside it plays out.

Albert Einstein's theories of relativity, developed in the early 20th century, threw such ethereal notions over a barrel. In relativity, time is a physical, dynamic thing, fused with space to form space-time – the fabric of the universe itself. And space-time isn't absolute, but relative, warped by motion and gravity. If you travel fast, or if you are in a strong gravitational field, it slows down.

The relativity of time has wide-ranging consequences. Because there is no unique way of defining its passage, there is no unique way of defining "now". Einstein concluded that all "nows" – past, present and future – must exist simultaneously, a picture known as the block universe that is completely at odds with our intuitions.

That mismatch occurs because, in our universe, the speed of light is finite. We can only reach certain times within a certain, well, time, so we can never achieve that God-like block-universe view. "In practice, causality limits what we can perceive in a very strict

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way, and our experience and anything that affects us is limited strongly by causality," says cosmologist Katie Mack at North Carolina State University.

The mysteries don't stop there. By making time part of the physical fabric of a universe that, as far as we can tell, began in a big bang some 13.8 billion years ago, Einstein's theory of general relativity implies that time itself had a beginning – and perhaps an end, too (see "Will time ever end?", page 48). There can be no eternal metronome ticking outside the universe as quantum theory implies, because such a source would have to exist outside space and time itself. This sets up a currently unbridgeable divide between relativity and quantum theory. In attempting to cross it, researchers such as Eichhorn hope to make progress towards a more unified picture of physics – one that would have to have a very different conception of time.

Many "quantum gravity" theories propose that if you could zoom in very close to the fabric of Einstein's space-time, to a fine-grained level known as the Planck scale, you would discover a substructure – a kind of quantum pixelation. That would open up entirely new possibilities. "It may very well be that the quantum structure of space and time is different in the presence of matter than it is if you're just thinking of sort of a universe which contains just space and time," says Eichhorn.

Not everyone thinks we need to go that far. Some see an avenue to finding the nature of time in a better understanding of quantum theory. Or perhaps time is itself a mirage. Like the colour or pattern of a tree leaf, time might be something of no significance, says Mack, the passage of which we invent to make sense of local patterns around us and our own lives.

After all, we never measure time itself, but rather regular changes – be it the passage of the seasons, the swing of a pendulum or the oscillation of a caesium atom – that we reverse-engineer into some mysterious thing we call "time". "It's something that we see, and that appears to be there," says Mack. "It may not matter to the cosmos."

RICHARD WEBB

00:02 WHY DOES TIME ONLY GO ONE WAY?

AS MUCH AS we may want to, we cannot go back in time. Is this just our current reality, or is the direction of time fixed by the laws of the universe?

One clue to explain this "arrow" of time is the second law of thermodynamics. This states that entropy – a measure of disorder in a system, loosely speaking – always tends to increase. Unless you put work into a system to maintain order, like tidying your bedroom, things will get messier.

While most physicists agree that there is a link between entropy and the arrow of time, how they relate is disputed. Some physicists think increasing entropy gives time its arrow, while some say the arrow is just an illusion. Others think we lack a basic understanding of time and, perhaps, marrying the quantum and classical worlds together will lead us to a new way of thinking about it. Some theories do away with entropy in the picture of time altogether.

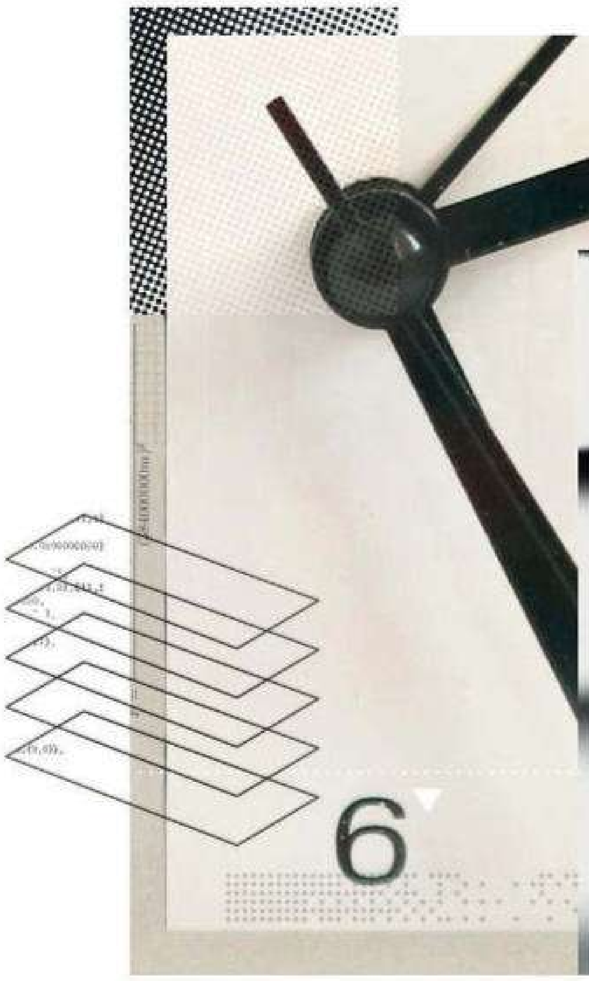
While on the macroscale, entropy and the laws of thermodynamics go some way to explaining why things go in one direction, the arrow of time was a puzzle on the small scale for many years. In fact, microscopic interactions can and do occur both forwards and in reverse. To us, this may seem strange. "Our intuition about time tends to be very bad," says Gavin Crooks at the University of California, Berkeley, "because we're sort of embedded in it."

But Crooks has shown that entropy plays a role on the small scale, too. Take any chemical reaction: its efficiency is always limited by microscopic rebellions, where the reverse reaction starts to take place. Crooks has developed a series of theorems that quantify the difference in the probability for reactions going forwards or backwards, based on the difference in entropy produced (see "Quantum motors", right), showing that there is an arrow of time on the micro scale.

Could we ever travel back in time? The absence of hordes of tourists from the future suggests not. However, some solutions to the equations of general relativity appear to provide a route to the past.

In Einstein's theory, the acceleration towards massive objects caused by a gravitational field is described as a curvature in space-time itself. Curve something enough, with enough gravity, and you could form a loop. These closed time-like curvatures (CTCs) crop up in various theoretical descriptions of the universe, from swirling dust to spinning cosmic strings, which are one-dimensional blips in space-time that could span astronomical distances.

"The arrow of time leads forward, as measured locally by the observer,



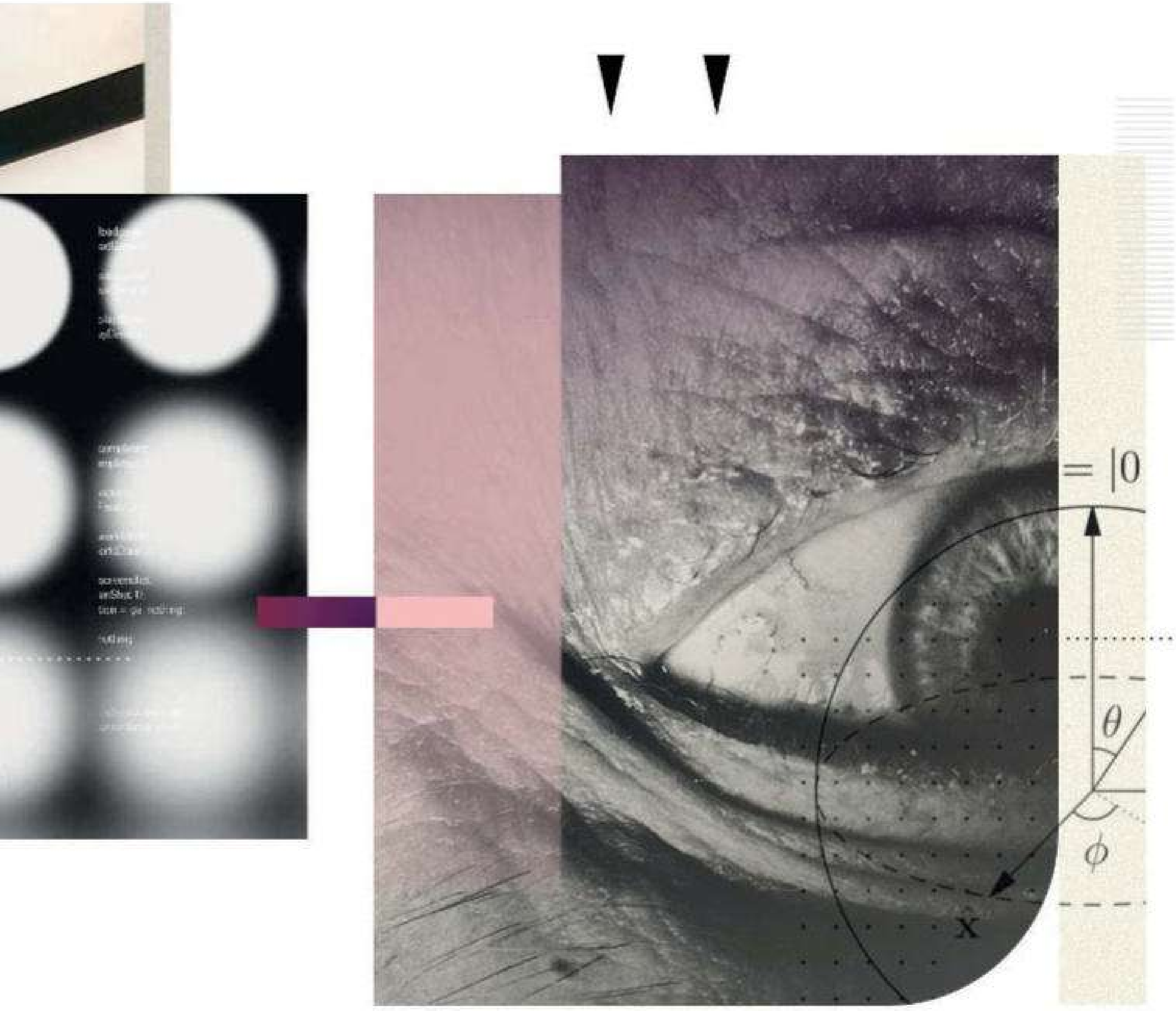
but globally he or she may return to an event in the past," says Francisco Lobo at the University of Lisbon in Portugal. This could open the door to all manner of mischief, such as the paradox of killing your own grandfather before your father was born. Fortunately, most scenarios that lead to CTCs are deemed impossible to physically occur.

"It is extremely unlikely that CTCs exist naturally in our universe," says Lobo. However, he leaves open the possibility that if an infinitely advanced civilisation could construct, for instance, a traversable wormhole, a tunnel between two black holes, then who knows? Maybe they could create a CTC and travel backwards in time after all.

ANNA DEMMING

QUANTUM MOTORS

In the 1990s, Gavin Crooks at the University of California, Berkeley, showed that entropy can have effects at very small scales. While they provoked a lot of debate at first, today these "fluctuation theorems" are well-established tools that provide insights in, for example, molecular biology. One recently revealed implication in quantum mechanics is that entanglement, where the states of two quantum objects are intrinsically entwined, can act as a resource akin to low entropy. Moving from a low entropy state to a higher one can power a motor, as it does when boiling water in a steam engine. "You can drive an engine with entanglement," as Crooks puts it. AD



00:03 HOW DO WE SENSE TIME?

EVER WALKED INTO the kitchen at the exact moment the oven beeps to say your dinner is ready? Most of us can estimate time passing with amazing precision thanks to a complex network of neural mechanisms. Over the past five years, our understanding of these has expanded rapidly, making it clear there is no single timekeeper in our brains. Nor is there a particular neural pathway that relates to time, as there is for other senses, such as smell or sight.

Some timekeeping happens unconsciously – our bodies have circadian rhythms that help biological processes occur at the right time of day (see "Can we live without time?", page 47). But mechanisms in our brain also contribute to our ability to sense the passing of time.

Let's start with "time cells". These reside in the hippocampus – a brain region involved in memory – and were first discovered in rats in 2018. Recently, time cells were also identified in humans by Bradley Lega at the University of Texas Southwestern Medical Center and his colleagues. Lega says that to understand what time cells do, first we need to consider "place cells" – brain cells that mark where in a spatial environment an animal is. If the animal walks along a linear tunnel, place cells would fire in a linear manner. Time cells do something similar, but for the passage of time.

When you are at an event – a movie or a dinner party, for instance – your brain will recognise this as a specific, or notable, chunk of time that neuroscientists call an "episode". In many cases, our brains know how long each episode is likely to be. "The brain has a rough template of most situations," says Lega. Armed with this knowledge, each time cell will fire in different windows during each episode. One might fire after 10 seconds, another at 2 minutes, and so on.

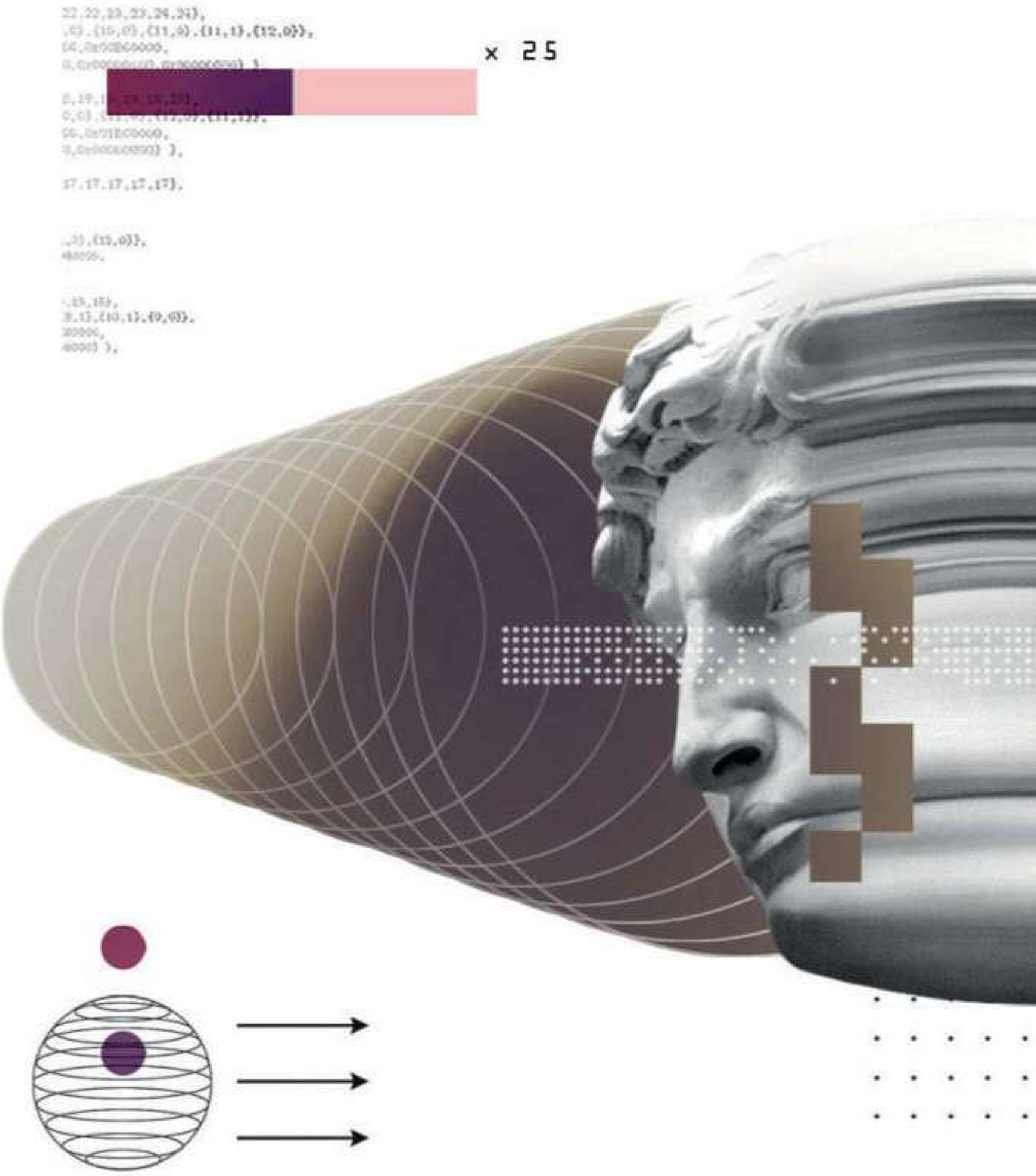
Time cells might explain why certain experiences feel like they happen faster than others (see "What affects our perception of time?", overleaf). Lega says the subjective experience of time may depend on how many episodes you are creating, and the detail you assign to each one. In an intense experience, your brain might create multiple episodes with many time cells associated with many › events, making time appear to slow down.

To track the passing of time, we may also need "ramping cells". Whereas time cells wait until it is their turn to fire, a ramping cell will fire intensely at the beginning of an episode, then gradually slow down. "Ramping cells will coordinate with time cells," says Lega. "They are two complementary ways of mapping temporal information."

So how do we stitch together the passage of time? The brain combines information from place cells about where an event is happening and sensory information about what is going on – what a person's perfume was, what they were talking about. Then, add in the time and ramping cell activity and the brain can put all the information into the appropriate time frame. This data is packaged up into episodic memories and stored, allowing us to perceive the temporal order of our lives.

This is the leading theory. But there may be other mechanisms involved, too, says Lega. Theta rhythms – waves of brain activity that oscillate at around 4 to 8 hertz – may also timestamp activities, depending on where within the wave they occur. "Some researchers believe the brain can tell time without time and ramping cells entirely" he says.

HELEN THOMSON



HOW DO ANIMALS SENSE TIME?

There is one dog year to every seven human years, so the saying goes. But does that mean one dog year feels like seven? Research suggests that time perception varies across all animals, and that their body mass and metabolic rate are the determining factors. Kevin Healy, then at Trinity College Dublin in Ireland, and his colleagues used a technique called critical flicker fusion frequency, which measures the speed at which the eye can process a flashing light before it sees it as constantly on. Healy's team found that smaller animals perceive time as if it is passing in slow motion because they see more information in 1 second than larger mammals such as an elephant. Further analysis showed that a high metabolism and small body size were also associated with the ability to take in more information and thereby sensing time passing more slowly. HT

00:04 WHAT AFFECTS OUR PERCEPTION OF TIME?

WHEN WE ARE children, short time periods represent a much larger chunk of our lives so far, compared with when we are older. This may lead a 5-year-old to feel that a year is an intolerable time to wait for Christmas, while for an adult, those 365 days fly by.

But there is more to our puzzling contractions of time than that. Some of it is in the brain. Adrian Bejan at Duke University in North Carolina says the brain's processing speed slows as we age – caused by the greater complexity of our neural networks that means signals travel greater distances. Our ageing brain captures less information per second, so packs less temporal information into one block of time, or "episode" (see "How do we sense time?", page 41). This can create the illusion that time has sped up. When we are younger, experiencing things for the first time may pack more into each episode. Like a slow-motion camera capturing thousands of images per second, it crams more into each time period and your subjective experience is of time passing more slowly.

Moment to moment, our emotional state can affect how we perceive time passing, too. It seems to fly when you are having fun and drags when you are bored. This may be to do with how our body processes time. The theory of "embodied cognition" says it is the processing of physical sensations that creates our perception of the world around us, including our sense of time. The body has numerous

rhythms, after all – from the beating of the heart to the hunger in our stomach – that might all give the brain a sense of how much time has passed.

We know that the brain integrates our bodily signals in a region known as the insula, located deep in the brain between the frontal and temporal lobes. This is essential for our sense of self and the construction of conscious experience, which must include some sense of time passing.

In one experiment, Marc Wittmann at the Institute for Frontier Areas in Psychology and Mental Health in Freiburg, Germany, asked people to replicate the length of high-pitched tones while he measured their neural activity in an fMRI scanner. During this task, participants showed more heightened activity in the insula than when they did a control task in which they pressed a button as soon as the tone had stopped. It looked like they were using their bodies' signals to gauge how much time had passed.

According to this idea, anything that directs more attention to our bodies should make time seem to slow. This might explain why time crawls when we are hungry or cold. "If you don't have distraction, you start attending to your bodily self," says Wittmann, "and time drags." If you focus your attention on something else, you are no longer listening so intently to those bodily signals, and time seems to speed up.

DAVID ROBSON

00:05 HOW MUCH TIME DOES EVOLUTION TAKE?

"Many of the great mysteries in evolution are not why change occurs, but why it fails to occur"

BY THE YARDSTICK of a human lifetime, time itself is dizzyingly long. If you condensed the entire 4.5 billion years of Earth's existence into a 24-hour period, more than 3 million years would pass each minute. The dinosaurs would go extinct at 11.39 pm and 48 seconds. Human history would begin two-tenths of a second before midnight.

The vast timescales at play in the universe's past are counter-intuitive. Even when the early pioneers of geology and evolutionary biology had proved beyond doubt that Earth was very, very ancient, it was still widely believed to be no more than a few tens of centuries old. Some people still cling to that belief today.

Charles Darwin, as usual, was ahead of his time. He realised that a few thousand years were nowhere near enough to incrementally transform, say, a primitive fish into a bird of paradise or a tiny weed into a mighty oak. Aeons were in order. As he wrote in *On the Origin of Species*, "we see nothing of these slow changes in progress, until the hand of time has marked the long lapse of ages".

That was the dominant view for a long time, says Matthew Pennell at the University of British Columbia in Canada. Indeed, biologists fretted that the rate of evolution was too slow to account for the riot of biodiversity they observed in the world. Now, however, the problem has flipped on its head. "We basically found over the last 30 years that evolution over small timescales is way too fast to explain patterns of diversity at longer timescales," says Pennell. "Many of the great mysteries in evolution are not why change occurs, but why it fails to occur," says Luke Harmon at the University of Idaho.

This is known as the paradox of stasis. Viewed through the lens of deep time – a period of a million years or more – evolutionary change happens glacially, if at all. But when biologists measure short-term rates of change – also called microevolution, which happens over years to decades – it is remarkably rapid.

A 2011 study of body size in birds, mammals and reptiles, for example, found that they can significantly expand and shrink in the space of a few generations. But these changes don't persist. It takes a million generations or more to evolve lasting changes, the study found. Darwin was right: natural selection is beavering away all the time, and yet evolution itself plods along like a stick-in-the-mud.

Why might that be? One possibility is evolution has accelerated over time and is now running faster than ever. That would explain why processes that can be observed over a few generations go fast, but ones requiring us to dig into the deep past went slower. This isn't implausible, says Harmon: pervasive human influence could be accelerating evolution, and some scientists have proposed that evolution also speeds up as the total biodiversity of Earth increases. But neither would explain why microevolution runs at the same rapid rate everywhere, rather than just in areas of high human influence or biodiversity.

A more likely explanation is that evolution responds rapidly to short-term environmental perturbations. These don't last long – and neither do the evolutionary changes they trigger. Over deep time, environments are very stable and species that are already fit, in the Darwinian sense, don't need to change to stay this way. They only make sustained leaps when major environmental shifts demand it.

This opens up the possibility that life on Earth is more adaptable to rapid environmental change than we might give it credit for. It is undoubtedly true, says Pennell, that adaption is happening fastest where human influence is strongest, such as in cities. But that isn't a get-out-of-jail-free card for our impact on nature. Evolution is up to the task, but it needs raw material in the form of genetic variation to work with, and that might not be available, especially with biodiversity already in steep decline. Mass extinction beckons – but it will be over in the blink of an eye. Recovery from mass extinctions usually takes several million years. That is just a few minutes on the endless showreel of deep time.

GRAHAM LAWTON

"I BUILT THE WORLD'S MOST PRECISE CLOCK"

AN INTERVIEW WITH PHYSICIST JUN YE ON ATOMIC CLOCKS, TIME DILATION AND TESTING THE LIMITS OF RELATIVITY

> "Clocks can potentially function as a new kind of detector for gravitational waves"

IF YOU EVER find yourself needing to check the time, you could do a lot worse than ask Jun Ye. Based at the JILA research institute in Boulder, Colorado, Ye has been working for 20 years on honing the design of that paragon of timepieces, the atomic clock. He says versions like his could help us snare more gravitational waves, check the fundamental constants of nature and perhaps push general relativity past breaking point.

Joshua Howgego: How do you make an atomic clock?

Jun Ye: People have made atomic clocks for many decades. The traditional way is to shine microwaves onto atoms, such as caesium or rubidium, to make their electrons flip from one quantum state – known as spin – to another at regular intervals. This flipping is the tick of the clock. In the clocks I make, the principle is the same. But we use laser light and shine it on strontium atoms, so electrons undergo energy transitions between two stable orbitals – and that's the tick.

How good is your clock?

There are three important performance metrics. First: how precise is your clock, or how well can you measure time? Second: how reproducible is it? This refers to whether you can get the same kind of measurement after a day, a week, a year. Third: how accurate is it? Is it a time that everyone can agree upon, after all systematic effects have been properly accounted for? This is quite different from precision. If we wanted to use these clocks as a standard for time, and we had one clock in Boulder and one in London, then they'd need to agree.

In terms of precision, our clock is a mind-boggling 100,000 times better than the best microwave-based atomic clock. It's been a tremendous improvement over the past 20 years. The clock is highly reproducible too. What's less clear, so far, is how well different clocks will agree.

I read your clock would only drop a second in the lifetime of the universe.

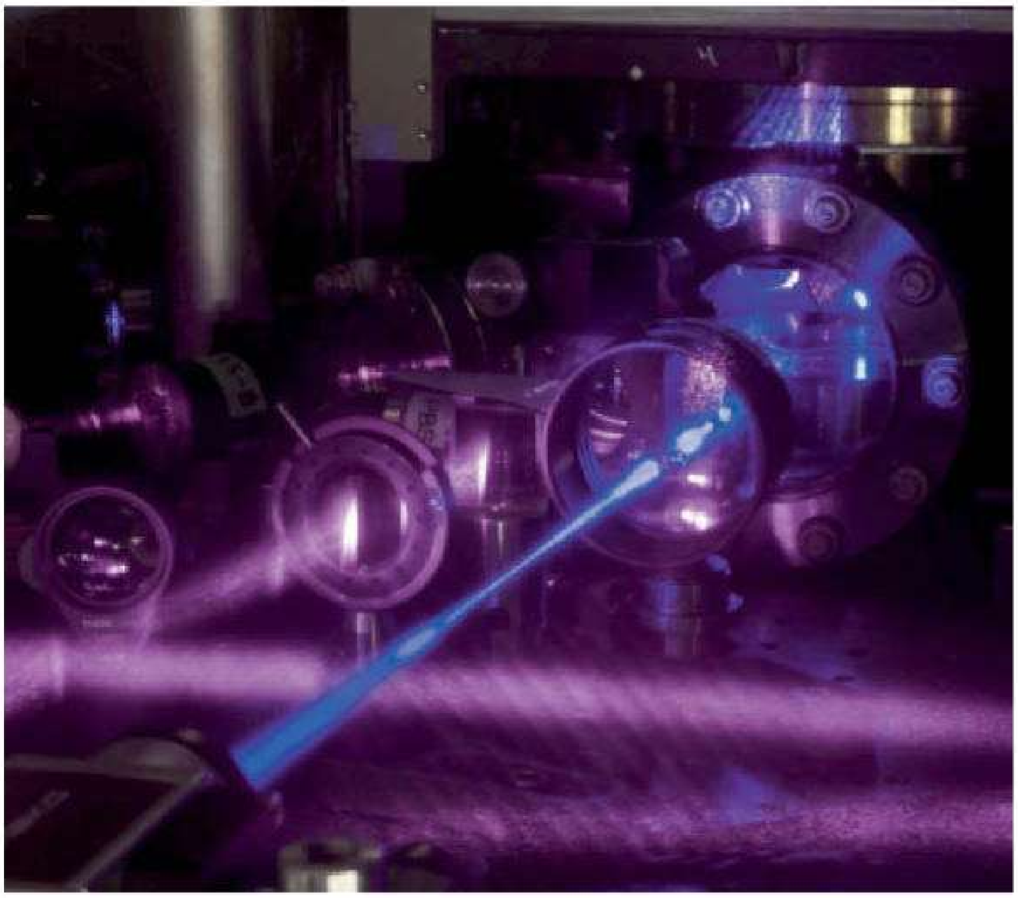
We're dealing with time intervals so small they are hard to grasp. Back in 2015, we did some calculations and converted the precision of the clock to a more understandable value. It came out as being precise to within 1 second in 14 billion years, which is the lifetime of the universe. Since then, the precision of the clock has got better – so now it is 1 second in multiple universe lifetimes.

Why make clocks this precise?

There are many secrets in the universe, many mysteries out there. It seems we're missing something fundamental about the way reality works. One way to try and get answers is to do experiments with particle colliders involving higher and higher energy. For that, you'd need about $40 billion and 30 years to construct yet another machine to smash particles,

LIFETOUCH INC.

Building very precise atomic clocks has been the goal of Jun Ye



G.E. MARTI, YE LABS/JILA

Jun Ye's strontium atomic clock is the most precise in the world

which isn't guaranteed to see something new. Precision clocks are a totally different and more accessible tool that will also allow us to search for new fundamental physics. One key area, for example, is time dilation on very small scales. If we can study this, it might tell us something new about the connection between quantum physics and gravity.

You recently used your clocks to measure time dilation.
When people first started to test if time dilation [the idea that clocks can experience time ticking at different speeds] was real, they compared clocks separated by kilometres using satellites and airplanes. There was a remarkable experiment by my colleague Dave Wineland in 2010 using clocks 33 centimetres apart and seeing dilation. Recently, we measured time dilation over a few hundred microns [millionths of a metre] with our strontium clock.

I think we need to go down further, so we can see time dilation over a few microns. This is where things get interesting. We'd potentially be able to see how things like entanglement [an intrinsic link particles can share after interacting] are affected by different curvatures in Earth's gravitational field.

Is there a limit to how accurate clocks will get?
The universe is always singing this symphony of gravitational waves borne out of collisions of black holes and such like. If your clock gets so precise that it can no longer be shielded from this omnipresent gravitational wave background, that will be the end of the road for the atomic clock. This is still many decades away, though.

We don't have to see this as a limitation. Clocks can potentially function as a new kind of detector for gravitational waves, a different way of observing them. One day we could have a network of clocks orbiting Earth, serving as a planet-scale antenna for gravitational waves. This might be able to pinpoint waves with sufficient precision that it could allow us to hear the echoes of the big bang from the edge of the universe. If we could get to that level, it would be fascinating.

JOSHUA HOWGEGO

00:06 CAN TIME LEAD US TO A THEORY OF EVERYTHING?

PHYSICS HAS A problem. In general relativity, time is entwined with space. It is relative, depending on speed or gravity. In quantum mechanics, however, time is an absolute. It is a smooth background into which we can plug our equations. How can time be these two conflicting things at once? "Solving the time problem is kind of the crucial issue really," says Emily Adlam at the Rotman Institute for Philosophy in Canada. If we want to unite these two incompatible theories into a theory of everything, something's got to give.

Lots of research aims to tackle this problem. Some treat quantum systems as relative, as in general relativity, while others view space-time as a quantum field, the fundamental entity that everything is made of in quantum mechanics. Now, a new approach is gaining interest. It is inspired by the famous Schrödinger's cat thought experiment, in which an unlucky feline is trapped in a box appearing to be both dead and alive. We know particles can be in a state of superposition, appearing to occupy many states at the same time until we measure them. What if those particles could act like a clock?

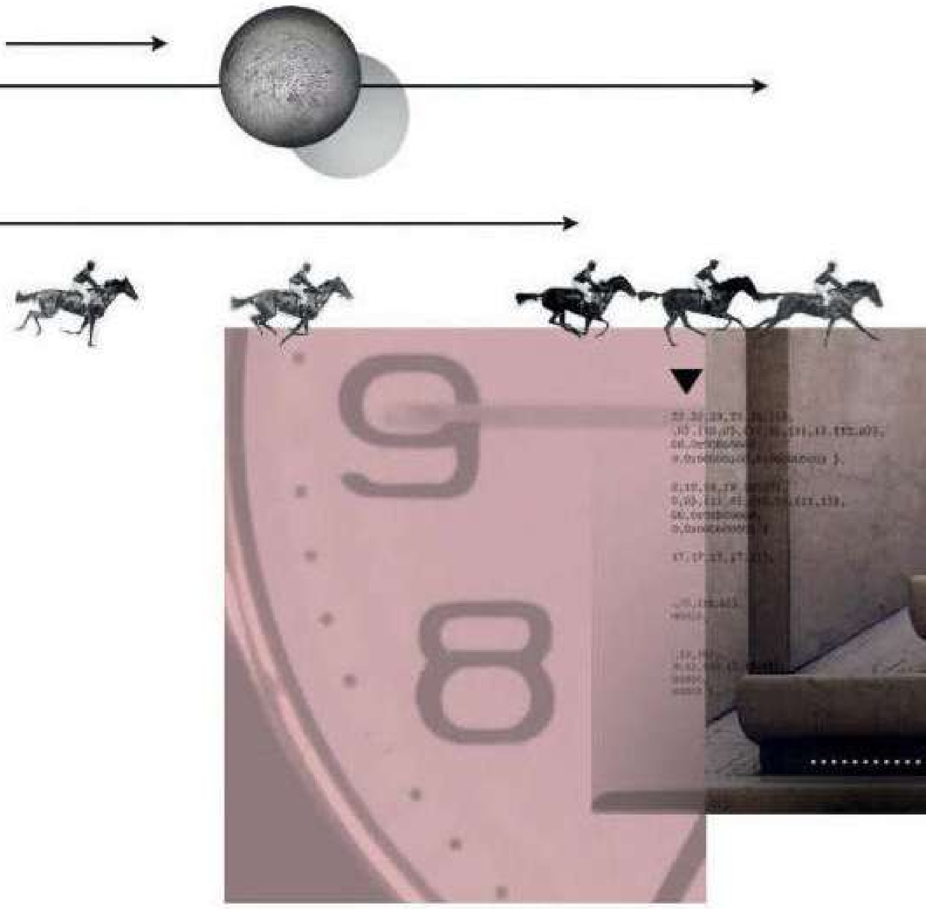
Chiara Marletto and Vlatko Vedral, both at the University of Oxford, UK, want to run an experiment. "It's like the Schrödinger's cat experiment," says Marletto, "but instead of a cat, you've got what, loosely speaking, acts like a clock." Take two masses large enough to interact through gravity and no other forces – say, molecules or tiny diamonds. Put both in a superposition. Each mass location in the experiment corresponds to a different space-time, according to general relativity.

If a clock can be in a superposition of ticking at different rates, it would indicate that time in quantum mechanics isn't fundamental, but relative to a given clock. The experiment is theoretical, but the pair hope it will be possible in five to 10 years. Since gravity would be the only thing connecting the masses, the pair says, seeing an entanglement would mean gravity must be a quantum phenomenon, giving clues about theories of quantum gravity that could help link relativity and quantum mechanics.

Others hope that putting an atomic clock in a superposition could test quantum gravity. Jun Ye at the JILA research institute in Boulder, Colorado, has recently shown that an atomic clock – a millimetre-tall cloud of atoms – ticks faster at the top, where Earth's gravity is ever so slightly weaker, than at the bottom (see interview, page 44). Ye hopes to make the clock around 20 times more precise in the next few years so that if the clock contains entangled atoms, gravity might break that entanglement. "Nobody has tested general relativity effects on the quantum scale," says Ye. Perhaps Schrödinger's clock – and not his cat – will be the way to do it, after all.

MIRIAM FRANKEL

> "To slow down time, you must always have something new, new, new"



00:07 HOW DO WE MAKE THE MOST OF OUR TIME?

REGARDLESS OF WHETHER it is counted by watching the sun pass across the sky or by an atomic clock, time is something we tend to want to extract the most value from before we die. That might be because of our unique awareness that we will inevitably die, which gives us a nagging sense that we are wasting what little time we have.

Subconscious fears about death drive much of human thought and behaviour, according to psychology's terror management theory. "The idea is that we would be overwhelmed with existential terror if we didn't have some way to manage it," says Sheldon Solomon, a psychologist at Skidmore College in Saratoga Springs, New York. And we manage it, the idea goes, by doing things that give us a sense of meaning and value, from believing in the afterlife to creating art.

For Solomon, this leads to a startling conclusion: that we are all just "anxious meat puppets tranquillised by culturally constructed trivialities". But while Solomon and his colleagues have shown that subtle reminders of death make people more likely to cling to their own world view and discriminate against outsiders, there is also a bright side to this awareness of the inevitability of death.

For starters, when a commodity is perceived as scarce, it becomes more valuable – and there is no reason to think time is any different. More specifically, research demonstrates that when people consciously reflect on death, they can boost their sense of self-worth, become more socially altruistic and more open to novel experiences.

New experiences, in turn, could help us savour our time, according to Marc Wittmann at the Institute for Frontier Areas of Psychology and Mental Health in Freiburg, Germany. When Wittmann and Sandra Lenhoff, both then at Ludwig Maximilian University in Munich, surveyed 499 people aged between 14 and 94, they found that older people felt that the past 10 years had passed faster than younger participants did. The reason can be found in the way our memory works (see "What affects our perception of time?", page 42). "The more memorable events you have stored in memory, the longer your subjective time," says Wittmann. So if you want to at least feel like you are making the most of your time, seek out novelty. "To slow down time, you must always have something new, new, new," says Wittmann.

But he also offers another strategy: recognising the need to switch your focus between past, present and future – the three "time dimensions". Take a teenager who doesn't want to study for a big exam:

they are stuck in the present at the expense of the future. "The focus of their lives is on a single time dimension," says Wittmann. What we should instead be aiming for is a healthy balance between all three. "Studies show those who have a more balanced time perspective are more successful in their professional life," says Wittmann, "but they're also in general happier."

DANIEL COSSINS

00:08 CAN WE LIVE WITHOUT TIME?

FROM THE MOMENT the alarm clock goes off in the morning, our lives are governed by time. Anyone yearning to escape the daily grind might start to wonder: what would happen if you ditched your watch and tried to live without time altogether?

Our bodies evolved to be in sync with the spinning of Earth on its axis, and this intimate connection is vital for our health. Daylight hits specialised cells on the retinas in our eyes that send signals about the time of day to a master clock in the brain (see "How do we sense time?", page 41). This, in turn, regulates the multitude of clocks ticking in cells and organs throughout the body, keeping us working as a coordinated whole.

With access to artificial light, many of us are staying awake when our brains and bodies are expecting sleep, throwing the body into uncoordinated chaos. For evidence on why this is bad news, look no further than night shift workers. This type of working pattern is so bad for our health that more than one report in the past few years has classified night shift work as "probably carcinogenic". It is also linked to increased risk of type 2 diabetes, heart disease, stroke, sleep problems and depression. Divorce rates are high in this group, too. Ditching your watch would probably be good for your health, and maybe even your relationship, as long as you also did away with artificial lighting and followed nature's clock of day and night.

But to truly experience a life without time, you'd want to do away with sunlight altogether. In 1962, French geologist Michel Siffre did just that, spending 63 days in a deep cave, cut off from all light except his torch. His escapade revealed that the body has its own clock that will shift if not kept in check by exposure to both light and dark. In a follow-up experiment, Siffre extended his cave time to an epic six months, during which his circadian rhythm stretched to 48 hours, his sense of time passing slowed and he also became depressed, much like those shift workers.

These experiments were just the start. Today, specialised sleep labs can create an alternative to the cave life that is more comfortable, but › just as removed from the real world. The floor is raised to insulate from noise, there are no windows or clocks and staff must be careful not to mention the time of day or wear clothes that could give anything away. Researchers must arrive clean shaven so as not to reveal the passage of time.

Without these time cues, artificial lighting and rigged clocks can be used to manipulate people's sense of time passing, and in doing so answer all sorts of questions. Among some of the most pressing are what happens to our mental health when our body clocks get out of sync, as well as looking at how the many clocks across the body might respond better to things like food or drugs at different times of the day.

Another benefit of timelessness, as Siffre reported in his caves, is an intense feeling of being in the present. This is something Marc Wittmann at the Institute for Frontier Areas of Psychology and Mental Health in Freiburg, Germany, has been exploring too, and so can you – no cave needed. Just book into a flotation tank.

The brain is effectively a prediction machine, making sense of what has just happened to anticipate what comes next. Without sensory inputs from the world around us, whether in a cave or a tank, this system breaks down. Without time, it seems, we may quite literally lose ourselves in the moment. "Initially, you have a very strong awareness of the body and time passes very slowly," says Wittmann. "But then, at some point, you get into this altered state of consciousness and then you lose your sense of self." Such an experience might be a fun distraction from the tyranny of the clock, but being able to track time helps bring people together too. So we should probably be wary of throwing away our watches for good.

CATHERINE DE LANGE

> "In a floatation tank, time passes very slowly and, at some point, you lose your sense of self"

00:09 WILL TIME EVER END?

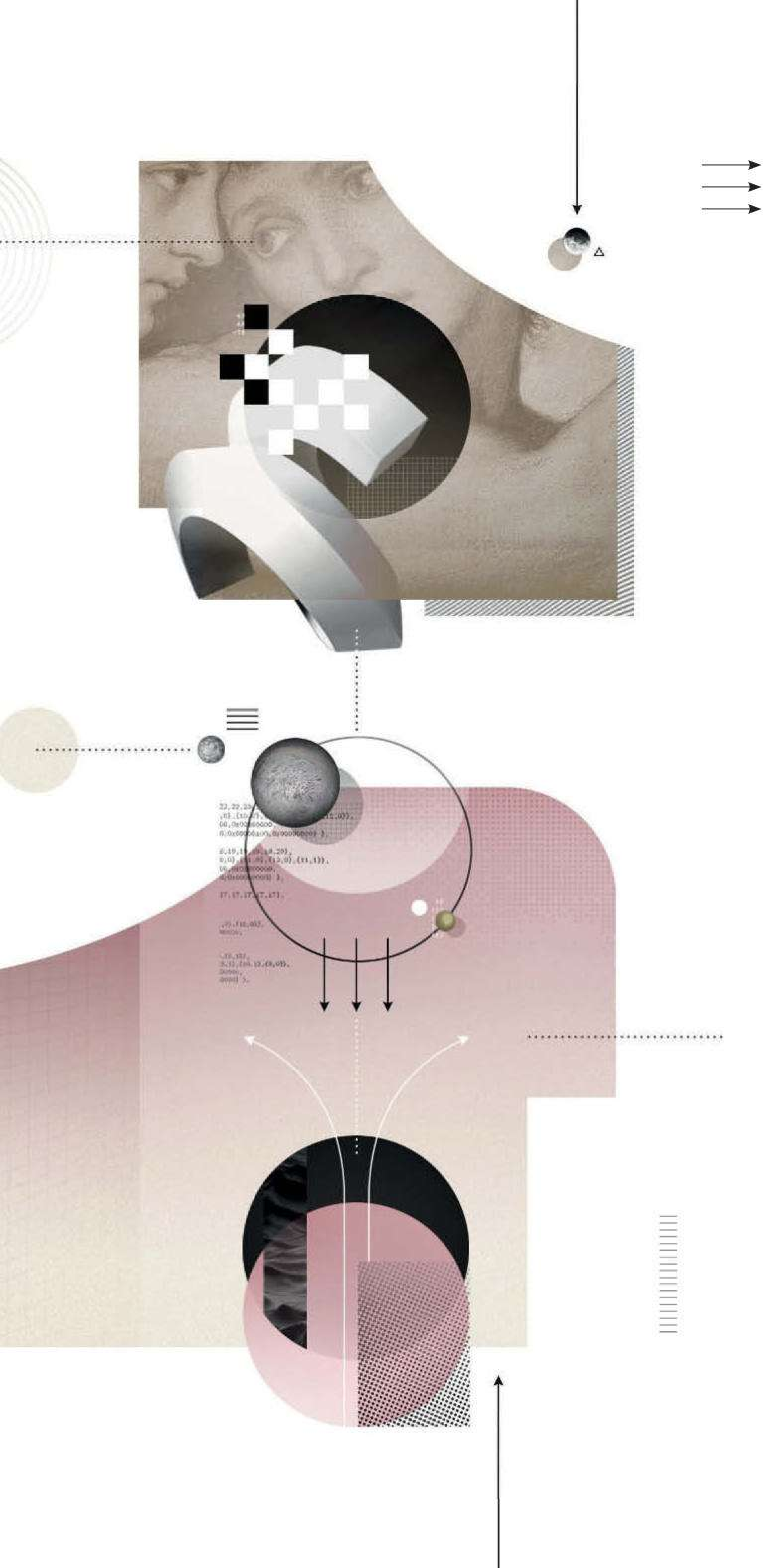
TO GRAPPLE WITH questions of time's end, let's first look the other way, to its beginning. Some 13.8 billion years ago, our universe, once thought to be eternal and unchanging, began. Space and time popped up spontaneously, out of nothing, in the big bang. Except we don't know for sure that is what happened. It is an extrapolation based on the equations of general relativity – Albert Einstein's theory of gravity – and our observations of a universe that, over billions of years, has been expanding and cooling from something denser and hotter.

Our observations take us back to some 380,000 years after a putative beginning, when the universe had cooled enough for the first atoms to form, sending radiation pinging through the cosmos. We hear that radiation today as the hiss of the cosmic microwave background.

With Einstein's theories, we can go back further, to the first microsecond, when the entire observable cosmos was about the size of our solar system. Beyond that, we are all at sea, with neither theory nor observations to help us. Wind Einstein's equations back enough, and you end up in a "singularity" of infinite temperature and density that seems to be a physical nonsense. Did time – did everything – really begin then?

The answer to that might depend on where you think the universe is going. "There are a couple possibilities there," says Katie Mack at North Carolina State University, author of *The End of Everything (Astrophysically speaking)*. "The expansion could continue forever, or it could stop and reverse."

That second, "big crunch", scenario has generally been more favoured. On its own, the density of matter in the universe seems to suggest that the pull of gravity will eventually overwhelm space-time's expansive momentum. The universe will reach a zenith of expansion and then begin contracting towards a kind of big bang in reverse.



That doesn't necessarily mean the end of time. A sub-genre of big-crunch scenarios proposes that the universe bounces back. In such "cyclic" cosmologies, time has no obvious end, but is constantly recreated – a process that presumably accounts for our own big bang.

Recent discoveries have swung the pendulum in favour of eternal expansion, however. A few billion years ago, the expansion of the universe started accelerating, spurred on by a mysterious agent known only as dark energy that overwhelmed gravity's contracting force. Wind this forwards, and the space between galaxies becomes so stretched that they gradually lose all causal contact with one another. The universe gets ever emptier and nothing useful can happen anymore – a scenario known as the heat death of the universe, or the "big freeze".

"It's not really clear what happens to time at that point," says Mack. "In principle, time still exists, it still keeps passing, but there's no future direction anymore." With nothing able to cause anything else, any definition of time rooted in causality ceases to have any meaning (see "What is time?", page 39).

There are more exotic alternatives. Perhaps the accelerating strength of dark energy will continue to increase and tear everything – galaxies, stars, atoms – apart before we reach a heat death, a scenario known as the "big rip". Even more dramatically, quantum field theory might allow for vacuum decay, in which a bubble of a different kind of space pops up in our universe and devours it.

Whether any of these things truly mean the end, however, depends on the beginning. Most cosmologists believe that our universe underwent a period of faster-than-light expansion in its first microsecond, which smoothed out its wrinkles, like an inflating balloon. This cosmic inflation is very hard to stop. In this scenario, universes keep budding off from one another to form a "multiverse" of causally disconnected universes. If this is the reality, it seems unlikely that ours was the "original" universe, and implausible to say that time began – or will end – with it. "If we get a heat death, then the arrow of time in our observable universe becomes meaningless," says Mack. "But that doesn't necessarily mean that there's not something happening much further away."

Of course, all of this depends on time having any true cosmic meaning. If, as some physicists speculate, time isn't real or fundamental to the universe, but is just of relevance to us to make sense of everything, then time will be over long before the universe ever is. ▮

RICHARD WEBB

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A cartoonist's take on the world p55

Feedback
Spare parts and leaky tanks: the week in weird p56

Twisteddoodles for *New Scientist*
Picturing the lighter side of life p56

Stargazing at home

Heavenly alignment

If you get up early, you may see five planets at once this June, lined up in order of their distance from the sun, says **Abigail Beall**

Abigail Beall is a feature editor at *New Scientist* and author of *The Art of Urban Astronomy*
@abbybeall

What you need

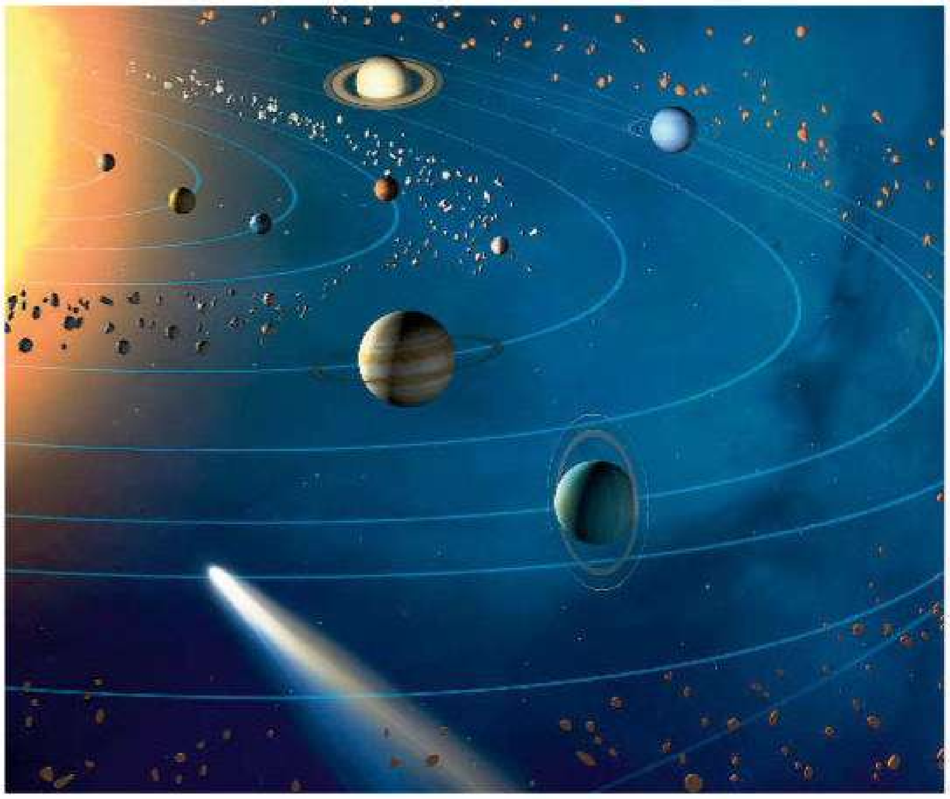
An alarm clock
Binoculars (optional)

WHILE the night sky changes with the seasons during Earth's orbit of the sun, the patterns of the stars remain consistent. The relative positions of the planets, on the other hand, do change, because each one works to a different schedule while travelling its own orbital path. Despite this, sometimes the stars – or, in this case, the planets – align, and we get a rare chance to see them all at once, at least the ones that are visible to the naked eye.

One such occasion is coming our way. Throughout late June, Mercury, Venus, Mars, Jupiter and Saturn will appear in our skies in a planetary line-up. The last time this happened was in 2020, and before that in 2016.

If you were to look down at our solar system from above during this alignment, the planets wouldn't be in a straight line, but they would be positioned on the correct side of the sun to reflect its light back towards us. This is what gives them the appearance of sitting in a line when viewed from here on Earth.

In a lovely coincidence, this time the planets will line up in order of their distance from the sun: Mercury will be closest to the horizon, followed by Venus, Mars, Jupiter and Saturn. This ordering should help you to spot them, particularly if you can identify the bright white glow of Venus or the reddish tinge of Mars.



SCIENCE PHOTO LIBRARY/ALAMY

To see the planets, you need to get up early. They will be in the eastern sky about 45 minutes to an hour before sunrise. In both the northern and southern hemispheres, they will appear near to the horizon, so a clear, unobstructed view of the lower sky is needed to see them properly.

Mercury will be the faintest of them all, and also closest to the horizon. Jupiter will be brighter than the brightest stars, and – like Venus – will appear white. Saturn will have a paler, yellower hue.

Those lucky enough to be away from light pollution with a clear, dark sky might also be able to spot Uranus, although they will need a pair of binoculars. To help you find it, note that Uranus will be next to the moon on 24 and 25 June, so look out for it then. The moon will be next to Venus on 26 June and will pass Mercury on 27 June.

If you are uncertain whether you are looking at a star or not, remember the general rule that stars twinkle, planets don't. The light from stars comes from so far away that it acts like a point source, similar to a laser beam. This means that, when compared to the light from planets, starlight is more susceptible to distortions in its direction when it enters our atmosphere. These distortions cause the apparent twinkle.

If that trick fails, as it sometimes does – because it can be difficult to tell whether a star is twinkling or not – don't be afraid to use a stargazing app to help you identify each of the five visible planets.

This is a very rare opportunity, so the early start will be worth it. ▮

These articles are posted each week at newscientist.com/maker

Stargazing at home appears every four weeks

Next week

Science of gardening

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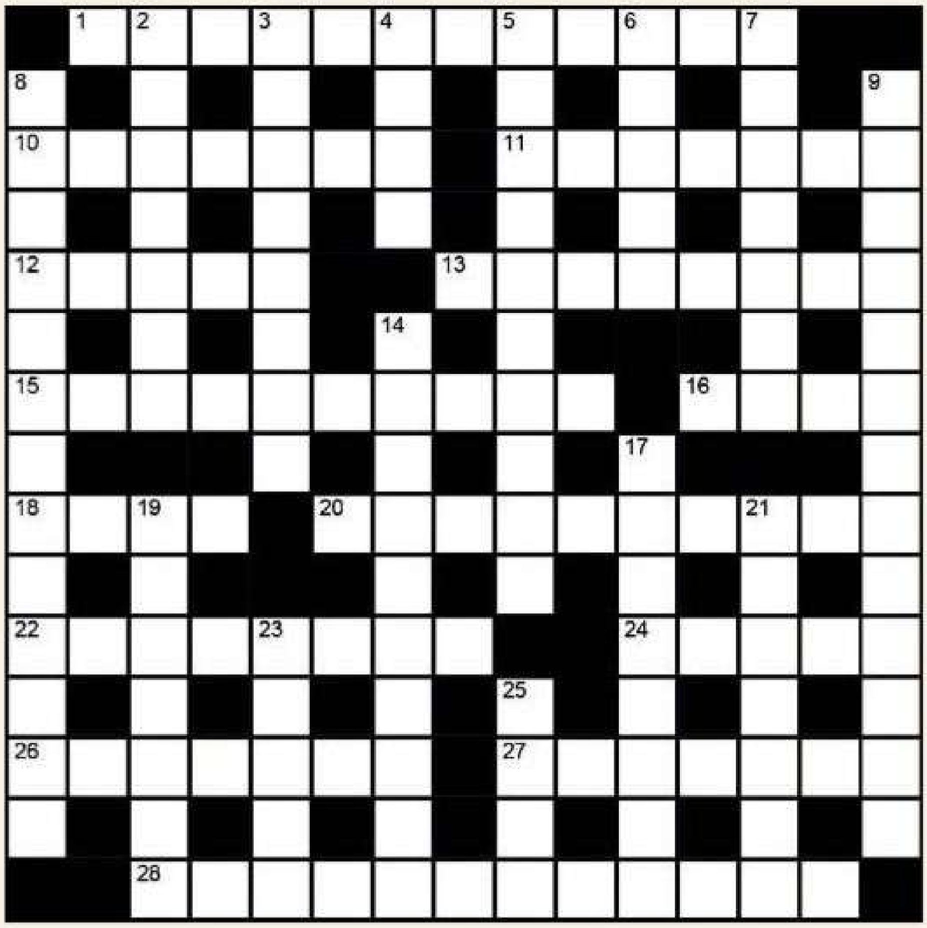
Quick crossword #110 *Set by Richard Smyth*



Scribble zone

Answers and the next cryptic crossword next week

ACROSS

1 The principle that equal volumes of gases have the same number of molecules (9,3)
10 Sergei ___, Soviet rocket engineer (7)
11 Otalgia (7)
12 Human sound (5)
13 Protective embryo casing (8)
15 Highest two-digit number (6-4)
16 Palaearctic duck, *Mergellus albellus* (4)
18 Above; greater than (4)
20 Student of living things (10)
22 Sustainable building block (8)
24 Mushrooms, for example (5)
26 Powdered rock, used as an abrasive (7)
27 Oxytocin or insulin, perhaps (7)
28 Modern interpretation of evolutionary theory (3-9)

DOWN

2 Updated or altered instalment of a software product, say (7)
3 King ___, razor pioneer (8)
4 Sir Humphry ___, Cornish chemist (4)
5 Greasy (10)
6 Primate that may be slow or slender (5)
7 Widespread Eurasian tree, *Ulmus glabra* (4,3)
8 Vast Botswana wetland (8,5)
9 Mushroom, *Agaricus xanthodermus* (6,7)
14 South polar region (10)
17 Anticoagulant (8)
19 Wear caused by water or wind (7)
21 Magmatic (7)
23 Prefix meaning rose-like or related to roses (5)
25 Melt; defrost (4)

Our crosswords are now solvable online
newscientist.com/crosswords

Quick quiz #156

1 In what year did the Carrington event take place?

2 The plant *Solanum tuberosum* gives rise to which foodstuff?

3 Where in the body would you find the abductor hallucis?

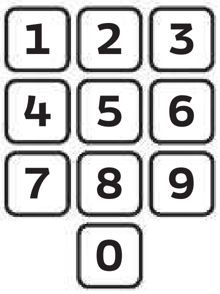
4 In physics, what does MOND stand for?

5 The name of which dinosaur genus translates to "fused lizard"?

Answers on page 55

Puzzle
set by Brian Hobbs

#172 Four got it



Emma Neesha is a forgetful sort, and she has just locked herself out of her house with her keys still inside.

Not to worry, she installed keypads on both her house and car for such occasions. Unfortunately, she has also forgotten the four-digit code to her house.

This shouldn't be a problem, because she keeps a code clue in her wallet. It says: "Four times the car's four-digit code."

Well, that is fine, but she has forgotten that one too. Fortunately, Emma is prepared: she has a clue written down for the car's code as well. Pulling that one out, it reads: "The reverse of the house code." Oh dear.

Can you help?

Solution next week

Watery origin

How and where was water first created?

Herman D'Hondt
Sydney, New South Wales, Australia
Water was first created in deep space, after hydrogen and oxygen first formed. All hydrogen atoms were created about 380,000 years after the big bang. Oxygen was created much later in the nuclear furnaces of stars, towards the end of their life cycles.

Stellar lives begin by converting hydrogen into helium. Then, as the hydrogen starts to run out, helium is converted into progressively heavier elements, including oxygen, all the way up to iron. Later, these elements are ejected from the stars.

In smaller stars, elements are released when the star goes through its red giant stage. In very heavy stars, this happens when the star explodes as a supernova.

When atoms of elements collide into each other in space, they can form compounds, such as water.

JURGEN FREUND/NATUREPL.COM

Crocodiles are still for long periods, so why don't their muscles weaken like ours do?

This week's new questions

Crocodile power **How do crocodiles maintain their explosive power despite being motionless for long periods, while if I am sedentary, my muscles weaken?** ***Sarah Shuff****, London, UK*

Infinity origin **The universe could be infinite in size, but how is it logically possible to attain an infinite size from a finite initial state?** ***Amir Malik****, London, UK*

> "The earliest evidence of water is a cloud containing water vapour from about 1.8 billion years after the big bang"

To make water, one atom of hydrogen and one oxygen atom combine to form a hydroxyl ion. The hydroxyl ion can combine with a second hydrogen atom, forming a stable molecule that doesn't react further. This takes a very long time, as atoms are highly spread out in space.

Currently, there are two ideas explaining how water eventually reached our planet. The first is that, when Earth formed as a red-hot fireball, it managed to hold on to some of the water that was present in the cloud of gas and dust that formed the solar system. The second says that most of the water was delivered after Earth cooled down and the planet was bombarded with asteroids and comets, the latter of which are sometimes called "dirty ice balls".

Eric Kvaalen
Les Essarts-le-Roi, France
Water first formed after oxygen appeared in the universe, and oxygen is created along with certain other elements by stars after they finish burning hydrogen. This would have been a couple hundred million years after the universe was born.

The earliest evidence of water in our universe is a cloud containing water vapour that is 12 billion light years away. In other words, water existed 1.8 billion years after the big bang.

While water initially manifested in space as a vapour, it can also form small ice crystals out in space. Liquid water would only have existed after the creation of planets that had the right temperature and pressure.

Mike Follows
Sutton Coldfield,
West Midlands, UK
Recent research suggests that water may have been first created less than 1 billion years after the big bang. This is thought to have taken place inside molecular gas clouds, which were nurseries for the second generation of stars.

The big bang created hydrogen, helium and a tiny bit of lithium and beryllium. Heavier elements, including oxygen, are forged inside stars and would have been much less abundant when the universe was only about 7 per cent of its current age. The relative scarcity of oxygen would have limited the speed of the chemical reactions that produced water, though the high density and temperature of the molecular gas clouds in which the reactions were taking place would have helped.

Most of the water in the universe is now created by reactions on the surface of interstellar grains of dust. In the early universe, there will have been much less dust in the interstellar medium because fewer dust-producing supernova explosions had occurred by then. In the absence of dust, a reaction between a hydrogen atom and an oxygen atom produces a hydroxyl molecule, which then reacts with another hydrogen atom to produce water.

We have yet to discover a better solvent than water for biochemical reactions, and the fact that it has probably been present throughout the universe for almost 13 billion years significantly increases the possibility of extraterrestrial life.

No joke

Do any other animals have a sense of humour? If you slipped on a banana skin, are there any creatures that would laugh?

Jonathan Wallace
Newcastle upon Tyne, UK
I believe that some of the great apes have demonstrated what appears to be a sense of humour. When shown conjuring tricks in zoos, they have been recorded displaying signs of astonishment followed by mirth at the seemingly impossible event they have witnessed. However, I don't know if any animals would laugh at someone slipping on a banana skin in the same way humans often do.

Paul Clark
London, UK
Having shared my home and life with an exceptionally intelligent cockatoo called Vanya for the past

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Tom Gauld
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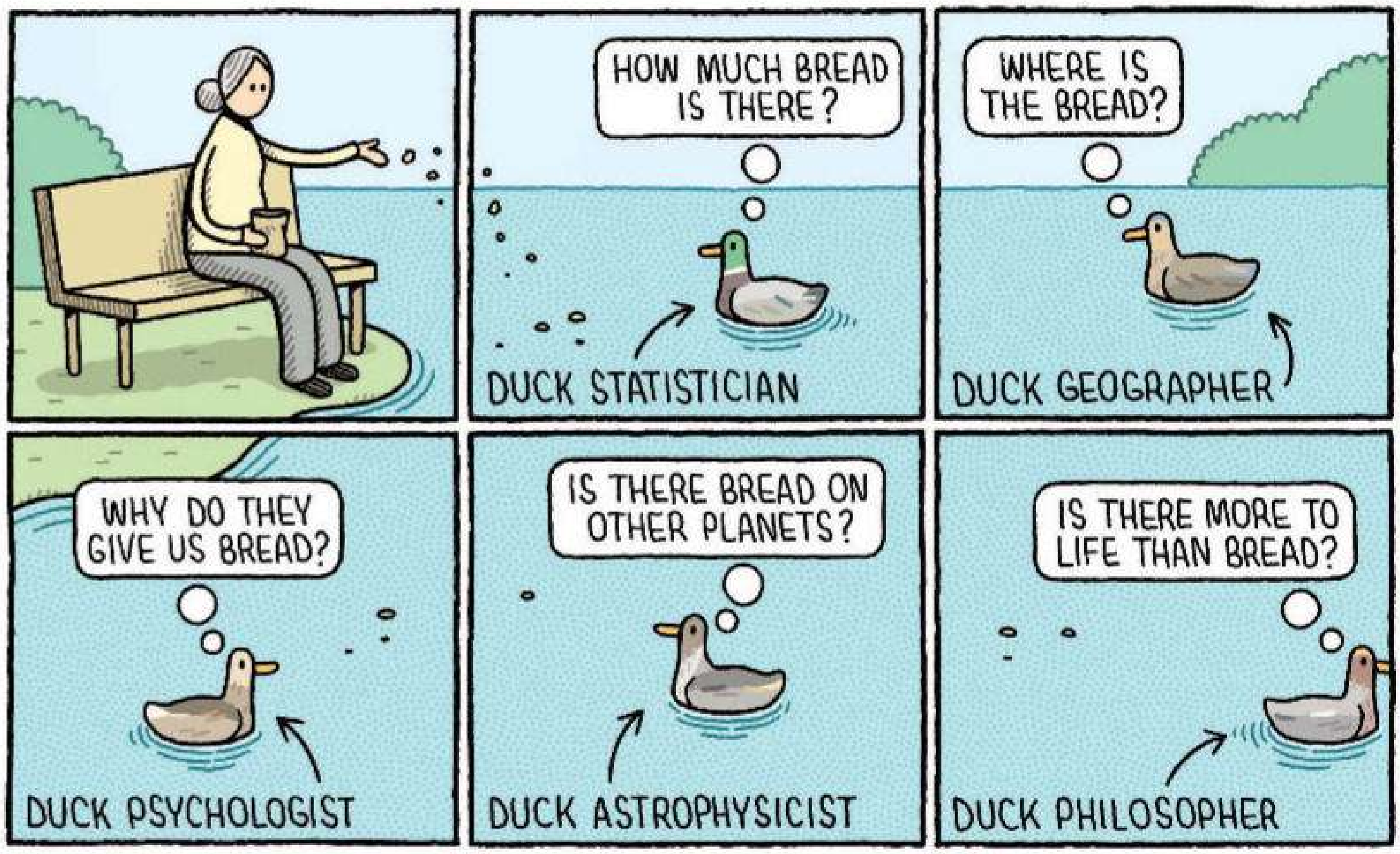
HOW MUCH BREAD IS THERE?
DUCK STATISTICIAN
WHERE IS THE BREAD?
DUCK GEOGRAPHER
WHY DO THEY GIVE US BREAD?
DUCK PSYCHOLOGIST
IS THERE BREAD ON OTHER PLANETS?
DUCK ASTROPHYSICIST
IS THERE MORE TO LIFE THAN BREAD?
DUCK PHILOSOPHER

12 years, I quickly learned that he seems to have the language skills of a 3-year-old human child.

Most remarkable, though, is his ability to "laugh" at a joke before humans in the room get it. I assume he reads facial and vocal cues – such as the smiles and intonations of those around him – to judge when his human company is heading towards communal laughter. He also mimics human laughter with accuracy.

So, you might say, how does that suggest he has a sense of humour, assuming he can't actually understand the nuances of the joke itself? Consider those awkward times when you have been in a group and didn't quite get a joke someone told. What did you do? Laugh. The ability to comprehend what a joke is and how we are expected to react is as important as getting the punchline itself.

> "The ability to understand what a joke is and how we should react is as important as getting the punchline itself"

John Davies
Lancaster, UK
Crows that tease cats often seem to enjoy it. The internet is full of videos in which one crow attracts a cat's attention while a fellow corvid creeps up behind the cat to tweak it by the tail.

Magpies will hunt and kill juvenile starlings, and in some cases, they have been found to just decapitate the prey and leave the bodies. This may indicate that they possess a dark sense of humour.

Nina Dougall
Malmsbury, Victoria, Australia
I think horses definitely do. I have been involved with both ponies and horses throughout my life, and have found, often to my embarrassment, that they enjoy setting up practical jokes.

Their favourite pranks are spilling slobber down the back of my neck and stomping in puddles while I lead them. Seemingly deliberate farts in my face, while intended as an insult, also result in mirth. These situations appear to be set up by the horse on purpose. The resultant wheezing asthmatic-cough-type noise they emit sounds a lot like laughter. Incidentally, they hate being laughed at.

Puppy love

Why do I love my dog when, in evolutionary terms, there are no benefits to me? (continued)

Sean O'Curneen
Brussels, Belgium
It is easy to see how domesticating wolves and loving dogs may have helped the development of human society, through improved hunting and farming.

Whether dog-loving humans could one day thrive over people who, say, love cats is a question I have thought carefully about.

Could walking a dog once or twice a day – while clutching a poo bag – ever become a necessity for human survival? I think it would be such a dystopian scenario that I, for one, would never want to see it. ▮

Answers

Quick quiz #156
Answers

1 1859
2 Potatoes
3 The foot
4 Modified Newtonian Dynamics
5 Ankylosaurus

Cryptic Crossword #85 *Answers*

ACROSS 1 Nicest, **4** Funkia, **9** Tangent, **10** Urine, **11** Crook, **12** Canthus, **13** Caterpillar, **18** Topical, **20** Bathe, **22** Fluke, **23** Notepad, **24** Erects, **25** Frazil

DOWN 1 Notice, **2** Congo, **3** Speckle, **5** U-turn, **6** Krishna, **7** Averse, **8** Stockpiling, **14** Ampoule, **15** Lobster, **16** Stifle, **17** Feudal, **19** Crest, **21** Topaz

#171 The magic number bracelet
Solution

The beads are 1, 3, 10, 2, 5.

There are 21 combinations you can make with five different numbers (the five individual numbers, five adjacent pairs, threes and fours, and the whole set of five numbers). This means there must be exactly one way to make each number from 1 to 21. To make 1 and 2, the bead numbers must include numbers 1 and 2. No bead can be >11 as 1+2+3+4+11=21. Three adjacent beads add to 17, so the other two add to four and must be 1 and 3, so there is no 4 bead.

That leaves two possible arrangements: 1,3,2,*,*, meaning there can't be a 5 or 6, leaving 1,3,2 (7/8), but no combination works. Or 1,3,*,2,*, so to make 5 there needs to be a 5 bead, leading to 1,3,10,2,5.

Spare parts

Crisis in the stationery cupboard as our veteran laptop's power plug finally expires. Now who will sell us a legacy LAVAFLO charging cable from 2003 (2nd edition)?

Seventy-eight per cent battery charge might just last us until we reach Uttoxeter (just off the UK's A50 road) and JCB's promising-sounding "World Parts Centre". Reader Paul Ticher finds comfort in its recent arrival, given "all the damage we are currently doing to our planet". (But you can see how his mind works: on the sad occasion of his father's passing, Paul tells us he called on the services of a local undertaker in Donegal, Ireland, called Seamus Shovlin.)

A chance, on this journey, to catch up on that never-diminishing pile of nominatively determined names, as spotted by our Valued Readers. Peter Slessenger kindly informs us that the UK's Nuclear Innovation Research Advisory Board was once chaired by Sue Ion.

Jeux avec Frontières

Down with this sort of thing! (Sixty-six per cent charge remaining...) This, anyway, was the tenor of the 30 May pronouncement of the Académie Française, which has been defending the French language against all comers (but mostly the English) since 1635. Fighting off the linguistic incursions of the gaming industry is its latest wheeze: "pro-gamer" has become "*joueur professionnel*", and don't say "streamer", say "*joueur-animateur en direct*". You may well consider this to be a quixotic effort by the Académie, unsuited to our globalised age. Feedback couldn't possibly comment – and has nothing but respect, in any event, for an organisation whose new appointees are given actual swords.

Twisteddoodles *for New Scientist*

SCIENTISTS, WE NEED A GOOD NEWS STORY
WE'VE NOTHING
NOTHING AT ALL?
IT'S MY BIRTHDAY?
Scientists celebrate Birthday
WHOLE LAB JOINS IN.
INSECT LARVAL STAGE CHOCOLATE CAKE
@twisteddoodles

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Send it to feedback@newscientist.com or New Scientist, Northcliffe House, 2 Derry Street, London W8 5TT
Consideration of items sent in the post will be delayed

War games

More games news. Remember the self-styled commander of a Challenger 2 tank who, in July 2021, posted a classified document on the multiplayer online battlefield game *War Thunder*? Or how, three months later, a French tank crew member shared a particularly juicy bit of the Leclerc main battle tank's classified manual with *War Thunder*'s user forum? It seems that the game's popularity now extends to China, and more particularly to the People's Liberation Army. On 31 May this year, the forum boasted a (swiftly deleted) picture of a Chinese DTC10-125 tungsten armour-piercing round, sitting atop a really quite revealing spec sheet. Now that is realism.

Inexpert opinion

Philippa Sandall's request for a word for anti-expert (4 June) throws up yet another real-world contender, this week from Simon Rundle: "sciolist", from the Late Latin *sciolus*, means "smatterer" (or, following Merriam-Webster, "one who speaks with spotty or superficial knowledge"). But why use an old word when a new one will do? Alan Carter's "ignert" proved especially welcome here, as did Mike Newman's suggestion that we combine "vacuous" and "orator" to give "vacuator".

But are there doughnuts?

Should the Franklin Marble be listed under the Baltimore Gneiss? And has a variant of the Franklin Marble been misidentified in the Reading Prong region?

Answers to these and other questions are sought in an upcoming forum series "regarding the process of updating Pennsylvania's geologic stratigraphic correlation chart!"

It certainly isn't our business to prick the enthusiasm packed into that charming exclamation mark, and Richard Bready, who brought this to our attention, has already nabbed his seat – who wouldn't on learning that each forum "will last around 4 hours with breaks"? Our guess is the DNCR Bureau of Geological Survey is like that diner in *Twin Peaks*, and serves – excuse me – a damn fine cup of coffee.

'A tiny thing'

Eighteen per cent battery life left, and we are only now getting to the Kentish phallus. (Stay calm: one expert opines that it isn't "an erect one".)

This is, to be serious for a second, a wonderful find: a silver Roman penis pendant, with stylised pubic hair, unearthed on New Year's Eve 2020 by metal detectorist Wendy Thompson on a farm in Kent, UK. ("I thought it was about 2,000 years old," she told *The Independent*, "and it was.")

The pendant, now officially declared treasure, might only be 3 centimetres long ("It was only a tiny thing really," said Thompson), but its antiquity is impressive, and the material from which it is made even more so: almost all Roman penises are made of copper.

Well, such necklaces were often given to children as lucky charms, and you don't want to give the little darlings anything too expensive, do you? It is a bit like figuring out how expensive a child's first mobile phone should be. Only, you know, with penises.

Under the wire

Five per cent battery left! Just enough to tell you about the EU's decision that, by late 2024, all small and medium-sized portable electronic devices must (4 per cent) come with USB Type-C charging ports. It is partly to reduce the 11 million kilograms of e-waste cluttering up Europe each year (3...), partly, we suspect, to annoy Apple (the company has already protested), but (2...) mostly to save Feedback's (1...) bacon when

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